DETERMINATION OF STACK GAS VELOCITY AND FLOW RATE IN EXHAUST STACKS, DUCTS, AND VENTS

Purpose

This Meteorology and Air Quality Group (MAQ) procedure describes the measurement of gas velocity and volumetric flow rate in LANL exhaust stacks, ducts, and vents using EPA Reference Methods 2 and 2C.

Scope

This procedure applies to all measurements of gas velocity and volumetric flow rate in LANL exhaust stacks for the Rad-NESHAP project.

In this Procedure

Hazard Control Plan

The hazard evaluation associated with this work is documented in HCP-MAQ-Office Work.

The non-office work steps in this procedure are not performed by MAQ personnel; thus no MAQ HCP has been prepared. JCNNM supervisors of personnel performing this process must ensure all applicable hazards analyses have been performed according to applicable requirements.

Signatures
(continued on next page)

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06/06/02

General information

Signatures, *continued*

Approved by:	Date:
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Attachments

Number	Attachment Title	No. of pages
1	EPA Reference Method Diagrams	8
2	Type-S Pitot Tube Equipment Form (Form 1)	2
3	Type-S Pitot Tube Calibration Worksheet (Form 3)	1
4	Velocity Measurement Input Form (Form 5-M)	2
5	Velocity Measurement Input Form (2 x 12 Round Stack or Duct) (Form 5-R)	1
6	Velocity Measurement Input Form (6 x 5 Rectangular Stack or Duct) (Form 5-S)	1
7	Velocity Measurement Input Continuation (Form 5-C)	1
8	Stack Flow Data Transcription and Entry Verification	1
9	Flow Measurement Calculation Form (Form 6)	2
10	Cross-Sectional Area Worksheet (Round Exhaust Stack/Duct) (Form 7-R)	1
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History of revision

This table lists the revision history and effective dates of this procedure.

Revision	Date	Description of Changes
0	4/24/98	New procedure replaces JCNNM procedure MOI 41-30-009, “Exhaust Stack Air Flow Measurements.”
1	2/1/00	Restructured text and attachments and revised many steps.
2	2/20/01	Incorporated use of the new Access database, added wording to clarify procedural steps, deleted reference to JCNNM Engineer, and minor editorial corrections.
3	6/4/02	Modify testing frequency and change group designation.

Who requires training to this procedure?

The following personnel require training before implementing this procedure:

- JCNNM technicians and staff members who perform flow measurements or support the MAQ Rad-NESHAP project exhaust stack flow measurement program.
- MAQ technicians and staff members who support the MAQ Rad-NESHAP project exhaust stack flow measurement program.

General information, continued

Training method

The training methods for this procedure are:

- **on-the-job** training for technicians and staff members *performing* flow measurements.
- "**self-study**" (**reading**) for technicians and staff members *supporting* the flow measurement program and for those previously trained to Revision 2 of this procedure.

Annual retraining is required and will be by "self-study" (reading). Training is documented in accordance with the procedure for training (MAQ-024).

Prerequisites

In addition to training to this procedure, the following training or surveillance programs are also required for technicians and staff members prior to performing flow measurements:

- Radiological Worker Training
- PU access list (when required)
- Industrial hygiene group full face respirator fitting and training program (when required)
- Site-specific training as required for each facility
- Basic Fall Protection; Course #13079
- MAQ-024, "Personnel Training"
- MAQ-026, "Deficiency Reporting and Correcting"

Recommended training

The following training is recommended, but not required:

- Tritium Safety
- Plutonium Safety
- Beryllium Health Hazards
- Hazard Communication Introduction

Definitions specific to this procedure

<u>ACFM</u>: Actual Cubic Feet per Minute, adjusted for temperature and pressure

<u>CFM</u>: Cubic feet per minute

<u>EDM</u>: Electronic Digital Manometer

<u>HEPA</u>: High Efficiency Particulate Air filter

<u>LIR</u>: Laboratory Implementation Requirement

<u>NIST</u>: National Institute of Standards and Technology

General information, continued

References

The following documents are referenced in this procedure:

National Codes and Standards

- 40 CFR 61 Subpart H, "National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities"
- 40 CFR 60 Appendix A Test Method 1, "Sample And Velocity Traverses For Stationary Sources"
- 40 CFR 60 Appendix A Test Method 1A, "Sample And Velocity Traverses For Stationary Sources With Small Stacks Or Ducts"
- 40 CFR 60 Appendix A Test Method 2, "Determination Of Stack Gas Velocity And Volumetric Flow Rate (Type S Pitot Tube)"
- 40 CFR 60 Appendix A Test Method 2C, "Determination Of Stack Gas Velocity And Volumetric Flow Rate In Small Stacks Or Ducts (Standard Pitot Tube)"
- 40 CFR 60 Appendix A Test Method 3, "Gas Analysis for Carbon Dioxide, Oxygen, Excess Air, and Dry Molecular Weight"
- 40 CFR 60 Appendix A Test Method 4, "Determination of Moisture Content in Stack Gases"
- 40 CFR 60 Appendix A Test Method 5, "Determination of Particulate Emissions From Stationary Sources"

Los Alamos National Laboratory Requirements

- LIR 230-03-01, "Facility Management Work Control"
- LIR 402-10-01, "Hazard Analysis and Control for Facility Work"
- LIR 402-704-01, "Contamination Control"

MAQ procedures and plan

- MAQ-RN, "Quality Assurance Project Plan for the Rad-NESHAP Compliance Project"
- MAQ-024, "Personnel Training"
- MAQ-026, "Deficiency Reporting and Correcting"

Literature

- Refer to the manufacturer's literature for each instrument
- Memorandum ESH-17:95-739, "Exhaust Stack Volumetric Flow Rate and Sample Flow Rate Reporting"
- Memorandum ESH-17:00-223, "Modified Traverse Spacing for Rad-NESHAP Monitored Stacks"

Work control

General

JCNNM coordinates all work performed in support of LANL's exhaust stack flow measurement program with the appropriate facility management unit in accordance with LIR 230-03-01, "Facility Management Work Control."

Work order

MAQ will annually fund appropriate cost codes to capture costs for routine exhaust stack flow measurements. All work performed will be reviewed and performed under the JCNNM preventive maintenance program.

Work orders for special flow measurements

All special flow measurements must be performed and charged to appropriate work orders. MAQ will set-up and fund a work order to capture costs for special flow measurements. All work performed will be reviewed and performed as required by LIR 230-03-01, "Facility Management Work Control."

Hazard analysis

It is the responsibility of JCNNM personnel, performing this procedure, to ensure all applicable hazards analyses have been performed according to applicable requirements (e.g., LIR 402-10-01, "Hazard Analysis and Control for Facility Work"). The responsible JCNNM employee refers to the activity hazard analysis (AHA) to know which personal protective equipment must be worn during maintenance, repair, and installation work.

Facility check-in and check-out

Special check-in and check-out procedures must be followed when working in certain facilities. The appropriate JCNNM employee shall ensure that all check-in and check-out procedures are followed and that the work crew is briefed prior to being dispatched to perform the work.

Work control, continued

Measurement frequency

The air flow in all LANL exhaust stacks which are sampled continuously for radionuclides should be measured:

- semi-annually, and;
- within forty-five days after a HEPA filter change or other pollution control device which could effect the flow rate through the stack, and;
- within forty-five days after a change to the ventilation system, or;
- at the direction of MAQ.

If a special flow measurement is performed outside of the normal semi-annual schedule, **do not reschedule** the next semi-annual measurement. For example, if a quarterly measurement is performed in January, and a HEPA filter change occurs in February, which results in a special flow measurement, perform the next routine measurement in July, not August.

In the event that a semi-annual flow measurement can not be performed during its scheduled month, **JCNNM** will be allowed to reschedule the measurement within 10 working days after the end of the scheduled month. The appropriate attachments for the late flow measurement must be submitted to MAQ immediately after the flow measurement and equipment verifications are completed. If a semi-annual flow measurement must be skipped due to factors beyond the control of MAQ and/or JCNNM, the **MAQ engineer** fully documents the circumstances surrounding the skipped flow measurement with an official memo to the file.

Duplicate flow measurements

Every six months, perform a duplicate flow measurement within one week of the original flow measurement. MAQ will randomly select one exhaust stack every six months at the beginning of the calendar year that is to be measured. This schedule may be modified during the year to account for any unforeseen scheduling problems. This duplicate flow measurement demonstrates the precision of the measurement methodology, as required by MAQ-RN ("Quality Assurance Project Plan for the Rad-NESHAP Compliance Project").

Safety and hazard analysis

ES&H hazard screening

As required by LIR 230-03-01, "Facility Management Work Control," **facility coordinators** (not JCNNM) perform an ES&H hazard screening in accordance with LIR 402-10-01, "Hazard Analysis and Control for Facility Work."

Potential hazards to consider

The following types of hazards may be present during air flow measurements and must be identified during the hazard analysis:

- radiation
- chemical emissions
- rotating machinery
- heights (e.g., roofs, scaffolding, bucket truck, etc.)
- weather (e.g., lightning, snow, ice, etc.)
- noise
- heat exposure
- falling objects
- compressed air

Radiological hazards

Before scheduling access to roof tops or the opening of stack measurement ports, determine if planned laboratory processes could be producing unusual radiological hazards during the time maintenance personnel plan to be working with the stacks.

Potentially contaminated equipment

Equipment used to measure airflow in potentially radioactive stacks must be cleared by the site radiological control technician in accordance with facility requirements and LIR 402-704-01, "Contamination Control." If radioactive contamination is detected, trained and qualified personnel must decontaminate the unit before it may be removed from the site.

Personal protection equipment

Safety shoes and safety glasses must be worn while performing all airflow measurements. The following additional personal protective equipment may be required:

- Hard hat
- Hearing protection
- Anti-contamination clothing including rubber gloves
- Respirator

Permits

All permits (e.g., radiation work permits) must be issued before work is released to the crafts.

Equipment specifications

Acceptable equipment

Specifications for equipment to be used to perform this procedure are given below. Other equipment meeting these specifications may be acceptable. **MAQ must obtain approval from EPA for substitute equipment not specified below.**

Type-S pitot tube for EPA Method 2

The Type-S pitot tube must be made of metal tubing (e.g., stainless steel) and configured as shown in Attachment 1, EPA Figure 2-1. The pitot tube must have a known coefficient determined as outlined below. The pitot tube must have an identification number permanently marked or engraved on the body of the tube.

NOTE: Do not use any Type-S pitot tube assembly that is constructed such that the impact pressure opening plane of the pitot tube is below the entry plane of the nozzle (see Attachment 1, Figure 2-6B).

Check tube alignment

Before initial use, check Type-S pitot tube alignment by performing the following steps:

Step	Action
1	Record the pitot tube ID number and length on the top of the Type-S Pitot Tube Equipment Form, Form 1 (Attachment 2).
2	Carefully examine the Type-S pitot tube in top, side, and end views to verify that the face openings of the tube are aligned within the specifications illustrated in Attachment 1, EPA Figure 2-2 or 2-3. The pitot tube may not be used if it fails to meet these alignment specifications.
3	Check the face openings of the pitot tube against Figure 2-2. Slight misalignments of the openings are permissible (see Figure 2-3).
4	Measure and record, in section 2 of the Type-S Pitot Tube Equipment Form, the external tubing diameter (dimension D_t, Figure 2-2b) and the base-to-opening plane distances (dimensions P_A and P_B, Figure 2-2b). **NOTE**: It is recommended that the external tubing diameter (dimension D_t, Figure 2-2b) be between 3/16 and 3/8 inch. There must be an equal distance from the base of each leg of the pitot tube to its face-opening plane (dimensions P_A and P_B, Figure 2-2b). It is recommended that this distance be between 1.05 and 1.50 times the external tubing diameter.

Steps continued on next page.

Equipment specifications, continued

Step	Action
5	Compare the measured dimensions. If D_t is between 3/16 and 3/8 in., and if P_A and P_B are equal and between 1.05 and 1.50 D_t, there are two possible options: 1. The pitot tube may be calibrated according to the procedure outlined in the chapter *Calibration of Type-S Pitot Tube*, or 2. a baseline (isolated tube) coefficient value of 0.84 may be assigned to the pitot tube. Record the required comparison and option information in sections 3 and 4 of the Type-S Pitot Tube Equipment Form (Form 1), Attachment 2. **NOTE**: If the pitot tube is part of an assembly, calibration may still be required, despite knowledge of the baseline coefficient value. If D_t, P_A, and P_B are outside the specified limits, the pitot tube must be calibrated as outlined in the chapter *Calibration of Type-S Pitot Tube*.

Using a standard pitot tube for EPA Method 2 or 2C

A standard pitot tube may be used if it is constructed according to the specifications below and assigned a baseline coefficient of 0.99. If the standard pitot tube is used as part of an assembly, the tube shall be in an interference-free arrangement. **EPA must approve the assembly before use.**

NOTE: The static and impact pressure holes of standard pitot tubes are susceptible to plugging in particulate-laden gas streams. Whenever a standard pitot tube is used to perform a traverse, adequate proof must be furnished that the openings of the pitot tube have not plugged up during the traverse period. The process for proving and documenting that the holes in the pitot tube have not plugged is described in the chapter *Measuring flow* in this procedure.

Acceptable standard pitot tube specifications

A standard pitot tube may be used if the tube has:

- a hemispherical (shown in Attachment 1, EPA Figure 2-4), ellipsoidal, or conical tip;
- a minimum of six diameters straight run (based upon D, the external diameter of the tube) between the tip and the static pressure holes;
- a minimum of eight diameters straight run between the static pressure holes and the centerline of the external tube following the 90-degree bend;
- static pressure holes of equal size (approximately 0.1 D) equally spaced in a piezometer ring configuration; and
- a ninety-degree bend with curved or mitered junction.

Equipment specifications, continued

Alternative pitot tube for EPA Method 2C

A modified hemispherical-nosed pitot tube, which features a shortened stem and enlarged impact and static pressure holes, may be used (Attachment 1, Figure 2C-1). Use a coefficient of 0.99 unless the pitot tube is calibrated. This modified standard type pitot tube is useful in particulate liquid droplet-laden gas streams when a "back purge" is ineffective. This type pitot tube has been approved for use by EPA when using Method 2C for flow measurements in stacks or ducts less than 12 inches in diameter.

Differential pressure gage

An inclined manometer or equivalent device must be used. For measurement of Δp values as low as 0.05 in. H_2O, use an inclined-vertical manometer having 0.01 inch H_2O divisions on the 0-to-1 inch inclined scale and 0.1 inch H_2O divisions on the 1-to-10 inch vertical scale.

If a differential pressure gage other than an inclined manometer is used (such as an EDM), the instrument calibration **must be checked after returning to the shop from performing stack flow measurements**.

A differential pressure gage of greater sensitivity must be used, **but must first be approved by EPA**, if any of the following occur:

- the arithmetic average of all VP readings at the traverse points in the stack is less than 0.05 in. H_2O
- for traverses of 12 or more points, more than 10 percent of the individual VP readings are below 0.05 in. H_2O
- for traverses of fewer than 12 points, more than one VP reading is below 0.05 in. H_2O

As an alternative to the above criteria, the following calculation may be performed to determine the need to use a more sensitive differential pressure gage:

$$T = \frac{\sum_{i=1}^{n} \sqrt{VPi + K}}{\sum_{i=1}^{n} \sqrt{VPi}}$$

Where: VP_i = Individual velocity head reading at a traverse point, in. H_2O
n = Total number of traverse points
K = 0.005 in. H_2O

If T is greater than 1.05, the velocity head data are unacceptable and a more sensitive differential pressure gage must be used.

Equipment specifications, continued

Temperature gage

Use a thermocouple, liquid-filled bulb thermometer, bimetallic thermometer, mercury-in-glass thermometer, or other gage, capable of measuring temperature to within 1.5 percent of the minimum absolute stack temperature in degrees Rankine. Attach the temperature gage to the pitot tube such that the sensor tip does not touch metal. The temperature gage must not interfere with the pitot tube face openings.

NOTE: Alternative positions for the temperature gage may be used if the pitot tube-temperature gage system is calibrated according to the chapter *Calibration of Type-S pitot tube*.

Pressure probe and gage

Use a piezometer tube and mercury- or water-filled U-tube manometer capable of measuring stack pressure to within 0.1 in. Hg. The static tip of a standard type pitot tube or one leg of a Type-S pitot tube (with face opening planes positioned parallel to the gas flow) may be used as the pressure probe.

Barometer

Use a mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 0.1 in. Hg. If the barometer is not located at the measuring site, adjust the barometric reading for elevation differences between the barometer (e.g., meteorology tower) and the sampling point. Adjust the reading minus 0.1 in. Hg per 100 foot elevation increase or plus 0.1 in. Hg per 100 foot elevation decrease.

Gas density determination equipment

Use EPA Method 3 equipment to determine the stack gas dry molecular weight. For processes emitting essentially air, an analysis need not be performed. Use a dry molecular weight of 29.0.

Moisture content determination equipment

Use a hand-held relative humidity meter capable of measuring the moisture content of the exhaust air to within ±1.5%.

NOTE: The relative humidity in the exhaust stack is measured for information purposes only. A value of 0% relative humidity is used in the calculations. This produces a slightly higher flow rate value than if the actual relative humidity was used. Please refer to memorandum ESH-17:95-739 for details.

Equipment specifications, continued

Special tools or equipment

The following tools and equipment are also needed to perform this procedure:

- Pitot tube level
- Pitot tube square
- Compressed air canister (non-ozone depleting)
- Hand pump capable of pressurizing (vacuum) to ±3 inches H_2O
- Wind tunnel meeting specifications given in the chapter *Calibration of Type-S pitot tube*.

Calibration of Type-S pitot tube

Calibration setup

If a Type-S pitot tube must be calibrated, one leg of the tube must be permanently marked “A” and the other “B.” This is done to duplicate the conditions in subsequent calibrations and during field use. Calibration must be performed in a flow system having the essential design features specified in the paragraphs below.

Flow system features

The flowing gas stream must be confined to a duct of definite cross-sectional area, either circular, oval, or rectangular. For circular cross sections, the minimum duct diameter is 12 in. For rectangular cross sections, the width (shorter side) must be at least 10 in.

Cross-sectional area

The cross-sectional area of the calibration duct must be constant over a distance of 10 or more duct diameters. For a rectangular cross section, use an equivalent diameter, calculated from the following equation, to determine the number of duct diameters:

$$D_e = \frac{2\,LW}{(L + W)}$$

Where:

D_e = Equivalent diameter.
L = Length.
W = Width.

To ensure the presence of stable, fully developed flow patterns at the calibration site, or "test section," the site must be located at least eight diameters downstream and two diameters upstream from the nearest disturbances.

NOTE: The eight- and two-diameter criteria are not absolute. Other test section locations may be used (subject to approval of EPA), provided that the flow at the test site is stable and demonstrably parallel to the duct axis.

Calibration of Type-S pitot tube, continued

Flow capacity

The flow system must have the capacity to generate a test-section velocity of approximately 3,500 ft/min. This velocity must be constant with time in order to guarantee steady flow during calibration. Note that Type-S pitot tube coefficients obtained by single-velocity calibration at 3,500 ft/min will generally be valid to ±3 percent for the measurement of velocities above l,000 ft/min and to ±5 to 6 percent for the measurement of velocities between 600 and l,000 ft/min. If a more precise correlation between C_p and velocity is desired, the flow system must have the capacity to generate at least four distinct, time-invariant test-section velocities covering the velocity range from 600 to 5,000 ft/min, and calibration data must be taken at regular velocity intervals over this range.

Probe locations

Two entry ports, one each for the standard and Type S pitot tubes, must be cut in the test section. The standard pitot entry port must be located slightly downstream of the Type S port, so that the standard and Type S impact openings will lie in the same cross-sectional plane during calibration. To facilitate alignment of the pitot tubes during calibration, it is advisable that the test section be constructed of plexiglass or some other transparent material.

Calibration method

This is a general process and must not be used without first referring to the chapter *Special Considerations* of this procedure. This process applies only to single-velocity calibration.

Steps to obtain calibration data

To obtain calibration data for the A and B sides of the Type-S pitot tube, perform the following steps:

Step	Action
1	Make sure that the manometer is properly filled and that the oil is free from contamination and is of the proper density. Inspect and leak-check all pitot lines; repair or replace if necessary.
2	Level and zero the manometer. Turn on the fan, and allow the flow to stabilize. Seal the Type-S entry port.
3	Ensure that the manometer is level and zeroed. Position the standard pitot tube at the calibration point (determined as described at the beginning of this chapter), and align the tube so that its tip is pointed directly into the flow. Care should be taken in aligning the tube to avoid yaw and pitch angles. Make sure that the entry port surrounding the tube is properly sealed.

Steps continued on next page.

Calibration of Type-S pitot tube, continued

Step	Action
4	Read VP_{std} and record the value in Type-S Pitot Tube Calibration Worksheet (Form 3), Attachment 3. Remove the standard pitot tube from the duct and disconnect it from the manometer. Seal the standard entry port.
5	Connect the Type-S pitot tube to the manometer. Open the Type-S entry port. Check the manometer level and zero. Insert and align the Type S pitot tube so that its A side impact opening is at the same point as was the standard pitot tube and is pointed directly into the flow. Make sure that the entry port surrounding the tube is properly sealed.
6	Read VP_s, and enter the value in the data table. Remove the Type-S pitot tube from the duct and disconnect it from the manometer.
7	Repeat steps 3 through 6 until three pairs of VP readings have been obtained.
8	Repeat steps 3 through 7 for the B side of the Type-S pitot tube.
9	Perform calibration calculations in the steps below.

Steps to perform calculations

To perform calibration calculations, perform the following steps:

Step	Action
1	Record the pitot tube ID number, the date, and the name and Z number of the person performing the calibration on the Type-S Pitot Tube Calibration Worksheet (Form 3), Attachment 3.
2	For each of the six pairs of VP readings (i.e., three from side A and three from side B) obtained, calculate the value of the Type-S pitot tube coefficient as follows: $$C_{p(s)} = C_{p(std)}\sqrt{\frac{VP_{std}}{VP_s}}$$ Where: $C_{p(s)}$ = Type-S pitot tube coefficient $C_{p(std)}$ = Standard pitot tube coefficient. Use 0.99 if the coefficient is unknown and the tube is designed according to the criteria of Attachment 4. VP_{std} = Velocity head measured by the standard pitot tube, in. H_20 VP_s = Velocity head measured by the Type S pitot tube, in. H_20
3	Calculate C_p (side A), the mean A-side coefficient, and C_p (side B), the mean B-side coefficient; calculate the difference between these two average values. Record these values on the Type-S Pitot Tube Calibration Worksheet (Form 3), Attachment 3.

Steps continued on next page.

Calibration of Type-S pitot tube, continued

Step	Action
4	Calculate the deviation of each of the three A-side values of $C_{p(s)}$ from $\overline{C}_p$ (side A), and the deviation of each B-side values of $C_{p(s)}$ from $\overline{C}_p$ (side B). Use the following equation: $$\text{Deviation} = C_{p_{(s)}} - \overline{C}_p(\text{A or B})$$ Record the deviation on the Type-S Pitot Tube Calibration Worksheet (Form 3).
5	Calculate σ, the average deviation from the mean, for both the A and B sides of the pitot tube. Use the following equation: $$\sigma(A\_or\_B) = \frac{\sum_{1}^{3} \left\| C_{p(s)} - \overline{C}_p(A\_or\_B) \right\|}{3}$$ Record the deviation on the Type-S Pitot Tube Calibration Worksheet (Form 3). Use the Type-S pitot tube only if the values of σ (side A) and σ (side B) are less than or equal to 0.01 and if the absolute value of the difference between $\overline{C}_p$ (A) and $\overline{C}_p$ (B) is 0.01 or less.

Special considerations for pitot tube calibration

Selection of calibration point – isolated pitot tube

When calibrating an isolated Type-S pitot tube, select a calibration point at or near the center of the duct, as described in this chapter, and follow the steps in the *Measuring flow* chapter of this procedure. The Type-S pitot coefficients so obtained [i.e., C_p (side A) and C_p (side B)] will be valid if either: (1) the isolated pitot tube is used; or (2) the pitot tube is used with other components (nozzle, thermocouple, sample probe) in an arrangement that is free from aerodynamic interference effects (see Attachment 1, EPA Figures 2-6 through 2-8).

Type-S pitot tube assemblies

During sample and velocity traverses, the isolated Type S pitot tube is not always used. In many instances, the pitot tube is used in combination with other source-sampling components (thermocouple, sampling probe, nozzle) as part of an "assembly."

The presence of other sampling components can sometimes affect the baseline value of the Type-S pitot tube coefficient. An assigned (or otherwise known) baseline coefficient value may or may not be valid for a given assembly. The baseline and assembly coefficient values will be identical only when the relative placement of the components in the assembly is such that aerodynamic interference effects are eliminated.

EPA Figures 2-6 through 2-8 in Attachment 1 illustrate interference-free component arrangements for Type-S pitot tubes having external tubing diameters between 3/16 and 3/8 in. Type-S pitot tube assemblies that fail to meet any or all of the specifications of Figures 2-6 through 2-8 must be calibrated according to the procedure outlined in the section, "Calibration of Type-S Pitot Tube" and Attachment 3. Prior to calibration, the values of the inter-component spacing (pitot-nozzle, pitot-thermocouple, pitot-probe sheath) must be measured and recorded.

Selection of calibration point – pitot tube thermocouple

For Type-S pitot tube-thermocouple combinations (without sample probe), select a calibration point at or near the center of the duct, as described in this chapter, and follow the steps in the *Measuring flow* chapter of this procedure. The coefficients so obtained will be valid if the pitot tube-thermocouple combination is used by itself or with other components in an interference-free arrangement (Attachment 1, EPA Figures 2-6 and 2-8).

Special considerations for pitot tube calibration, continued

Selection of calibration point – assemblies

For assemblies with sample probes, the calibration point should be located at or near the center of the duct; however, insertion of a probe sheath into a small duct may cause significant cross-sectional area blockage and yield incorrect coefficient values. To minimize the blockage effect, the calibration point may be a few inches off-center. The actual blockage effect will be negligible when the theoretical blockage, as determined by a projected-area model of the probe sheath, is 2 percent or less of the duct cross-sectional area for assemblies without external sheaths (EPA Figure 2-10a) and 3 percent or less for assemblies with external sheaths (EPA Figure 2-10b).

Assemblies with interference

For those probe assemblies for which pitot tube-nozzle interference is a factor (i.e., the pitot-nozzle separation distance fails to meet the specification illustrated in EPA Figure 2-6A), the value of $C_{p(s)}$ depends on the amount of free space between the tube and nozzle and is therefore a function of nozzle size. In these instances, separate calibrations must be performed with each of the commonly used nozzle sizes in place. The single-velocity calibration technique is acceptable for this purpose even though the larger nozzle sizes (> 1/4 in.) are not ordinarily used for isokinetic sampling at velocities around 3,000 ft/min, which is the calibration velocity. It is not necessary to draw an isokinetic sample during calibration.

Assemblies with only one orientation

For a probe assembly constructed such that its pitot tube is always used in the same orientation, only one side of the pitot tube must be calibrated (the side which will face the flow). The pitot tube must still meet the alignment specifications of Attachment 1, EPA Figure 2-2 or 2-3, and must have an average deviation(s) value of 0.01 or less (see the chapter *Calibration of Type-S Pitot Tubes*).

Field use

When a Type-S pitot tube (isolated or in an assembly) is used in the field, the appropriate coefficient value (whether assigned or obtained by calibration) must be used to perform velocity calculations. For calibrated Type-S pitot tubes, the A side coefficient must be used when the A side of the tube faces the flow and the B side coefficient must be used when the B side faces the flow. Using the arithmetic average of the A and B side coefficient values is also acceptable, irrespective of which side faces the flow.

Special considerations for pitot tube calibration, continued

Field use, *continued*

When a probe assembly is used to sample a small duct 12 to 36 in. diameter, the probe sheath sometimes blocks a significant part of the duct cross-section causing a reduction in the effective value of $C_{p(s)}$. Conventional pitot-sampling probe assemblies are not recommended for use in ducts having inside diameters smaller than 12 in.

Calibration of other equipment

Electronic Digital Manometer

An Electronic Digital Manometer (EDM) used (instead of an oil-gage manometer) to measure the airflow in the stacks must be calibrated annually by ESA-MT or the manufacturer. Calibration must be traceable to NIST standards.

At the end of the testing day, check the calibration of the EDM with an oil-gage manometer. Compare the VP readings of the EDM with those of an oil-gage manometer at a minimum of three points, approximately representing the range of VP values in the stack. If, at each point, the values of VP, as read by the EDM and oil-gage manometer, agree to within 5 percent, consider the EDM to be in proper calibration. Otherwise, the test series must either be voided, or procedures to adjust the measured VP values and final results must be used. **Procedures to adjust measured VP values and final results must be approved by EPA before use.**

Temperature gages

Temperature gages used to measure air temperature in stacks must be calibrated annually by ESA-MT. Calibrations must be traceable to NIST standards.

At the end of the testing day, calibrate dial thermometers, liquid-filled bulb thermometers, thermocouple-potentiometer systems, and other gages at a temperature within 10 percent of the average absolute stack temperature.

- The average absolute stack temperature is

  $$°R = °F + 460$$

- For temperatures up to 761 °F, use an ASTM mercury-in-glass reference thermometer, or equivalent, as the reference.

- If, during calibration, the absolute temperature measured with the gage being calibrated and the reference gage agree within 1.5 percent, the temperature data taken in the field is considered valid. Otherwise, the pollutant emission test must either be considered invalid or adjustments (if appropriate) to the test results must be made. **Any adjustments to the test results must be approved by EPA before the results may be used in emission calculations by MAQ.**

Calibration of other equipment, continued

Relative humidity meter

Relative humidity meters used to measure the moisture content of the air in the exhaust stack must be calibrated annually by ESA-MT. Calibrations must be traceable to NIST standards.

Even though a relative humidity measurement is taken for each flow measurement, a value of 0% relative humidity will be used to calculate the final flow rate. This results in a slightly higher volumetric flow rate than if the actual relative humidity value is used in the calculation. This practice is consistent with the built-in conservatism in the Rad-NESHAP program.

Barometer

Barometer calibration requirements are:

- The JCNNM barometer aneroid must be calibrated annually by ESA-MT or the manufacturer.
- The JCNNM barometer reading must be verified and corrected (accounting for elevation differences) semi-annually to the official MAQ meteorology section barometer.

Equipment calibrations

Documented proof of calibration must be available for all measurement tools and instruments.

Disposition of equipment

When program equipment is removed from service or disposed of, forward all original calibration certificates and any manufacturer's documentation to MAQ.

Measuring flow

Background

The average gas velocity in a stack is determined from the gas density and from measurement of the average velocity head.

Applicability

This procedure must be followed for measurement of the average velocity of a gas stream and for quantifying gas flow. This procedure does not apply at measurement sites that fail to meet the criteria of EPA Reference Method 1 or 1A. Also, this procedure cannot be used for direct measurement in cyclonic or swirling gas streams in excess of regulatory limits.

Exhaust stack measurement location (i.e., profile location)

MAQ will specify the location on the exhaust stack to perform airflow measurements. In addition, MAQ will specify the number of traverses, the number of measurement points, and their spacing along each traverse. When an exhaust stack or duct is not perfectly round, the traverse spacing is determined per memo ESH-17:00-223. The number of traverses and the number of measurement points defines the measurement matrix.

The measurement location must meet the criteria of EPA Reference Method 1. If field conditions have changed (e.g., flow disturbances have been added to the ventilation system at the measurement point), do not perform the flow measurement. Contact MAQ for further direction.

Field measurement forms

Record all measurement field data on the appropriate forms:

- Velocity Measurement Input Form (Form 5-M) (see example in Attachment 4)
- Velocity Measurement Input Form (2 x 12 Round Stack or Duct) (Form 5-R) (see example in Attachment 5)
- Velocity Measurement Input Form (6 x 5 Rectangular Stack or Duct) (Form 5-S) (see example in Attachment 6)
- Velocity Measurement Input Continuation Form (Form 5-C) (see example in Attachment 7), as necessary

Record all entries in ink. Correct any errors by striking through the erroneous entry with a single line and annotating the correct information in an empty space directly adjacent to the error. Initial the correction.

Measuring flow, continued

Measure stack cross-sectional area

The cross-sectional area of each measuring location must be known. This needs to be performed only once for each location. If the cross sectional area has not been previously measured, follow the steps below.

Steps to measure cross-sectional area

To measure the cross-sectional area at a measurement location, perform the following steps:

Step	Action
1	Make a rough sketch of the cross-sectional area on the stack or duct in section 1 of the “Cross-Sectional Area Worksheet (Round Exhaust Stack/Duct) (Form 7-R)” or “Cross-Sectional Area Worksheet (Rectangular Exhaust Stack/Duct) (Form 7-S)” (see examples in Attachments 10 or 11). Show: • the traverses • the orientation of the duct (vertical, horizontal) • label north/south/east/west, if appropriate • label up/down, if appropriate • the direction of air flow • indicate exterior items (i.e., the fan) which would help someone else align the traverses
2	Measure the inside duct dimensions. For round and oval stacks, measure each traverse diameter to the nearest 1/8 inch. For rectangular stacks, measure the widths (front and back face), and the depths (both sides) to the nearest 1/8 inch. Convert the fractional measurements to decimal format. For round stacks or ducts, calculate the average inside diameter. For oval stacks or ducts, record the actual measured diameters. Record this information in section 2 of the Cross-Sectional Area Worksheet (either Form 7-R or Form 7-S).

Steps continued on next page.

Measuring flow, continued

Step	Action
3	Calculate the area. Round: $Area = \pi\left[\frac{d}{2}\right]^2\left[\frac{1}{144}\right]$ sq feet Oval: $Area = \frac{\pi * d_1 * d_2}{576}$ sq feet Rectangular: $Area = \left[\frac{W1+W2}{2}\right]\left[\frac{D1+D2}{2}\right]\left[\frac{1}{144}\right]$ sq feet Do not round values during calculation. Round the final value for the area to 3 decimal places. Record the area in section 3 of the Exhaust Stack or Duct Cross-Sectional Area Worksheet (either Form 7-R or Form 7-S).
4	Sign and date the Cross-Sectional Area Worksheet (either Form 7-R or Form 7-S). Both the person making the measurements and the person performing the calculations must sign and date this form.

Field conditions

Only perform airflow measurements when an exhaust stack, duct, or vent is exhausting ambient air from a laboratory or facility.

Steps to measure flow

To measure flow in a stack, duct, or vent, perform the following steps:

Step	Action
Determining the location for performing measurements	
1	Obtain the location on the stack or duct for performing the measurement from MAQ. The location is given by the profile measurement number. **<u>NOTE:</u>** Acceptable locations are determined by MAQ by using EPA Method 1 for a stack or duct diameters 12 inches or larger; and by EPA Method 1A for diameters less than 12 inches, but not smaller than 4 in.
Preparing measurement input forms	
2	Record the TA, building, exhaust stack (ES) ID Number and exhaust fan(s) numbers on the top of the Velocity Measurement Input Form (Form 5-M) (see example in Attachment 4). Record the preventive maintenance ticket number, the profile number, the fan configuration, the type of measurement (semi-annual, special, other), and the test method used.

Steps continued on next page.

Measuring flow, continued

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>3</td><td>Record, on the bottom of the Velocity Measurement Input Form (Form 5-M) (see example in Attachment 4), the name and Z-number of the craftsman responsible for measuring and recording the flow measurement data.</td></tr>
<tr><td colspan="2">Selecting and preparing equipment</td></tr>
<tr><td>4</td><td>Select the correct pitot tube(s) for the stack(s) to be analyzed.

<table><tr><th>For stack or duct…</th><th>use…</th></tr><tr><td>≥ 12” diameter or ≥ 113 in.^{2} cross-sectional area</td><td>Type-S pitot tube or standard pitot tube.</td></tr><tr><td>< 12” diameter or < 113 in.^{2} but ≥ 4” diameter or ≥ 12.57 in.^{2} cross-sectional area</td><td>Standard pitot tube or approved alternative pitot tube. Do <u>not</u> use a Type-S pitot tube.</td></tr></table>
The tip of the tube(s) to be used must be free of any damage. Each tube must be long enough to reach all traverse points along the cross-section of the stack(s). Calculate the distances from the centerline of the pitot nozzle to each traverse point, and mark the tube with a felt-tipped pen so that the pitot can be correctly positioned from the hole in the stack wall to each traverse point. Then have a second qualified stack measurement craftsman independently verify these markings. Check the appropriate box in section 1 indicating traverse spacing has been verified.</td></tr>
<tr><td colspan="2">Recording equipment calibration</td></tr>
<tr><td>5</td><td>Record the following in section 1 of the Velocity Measurement Input Form (Form 5-M):
Manometer type (e.g., EDM), serial number, calibration expiration date;
Thermometer type, serial number, calibration expiration date;
Relative humidity meter, serial number, calibration expiration date;
Pitot tube type (e.g., Type-S), serial number (if applicable)
Verify that the EDM, relative humidity meter, and thermometer calibration certifications have not expired.</td></tr>
<tr><td colspan="2">Verifying exhaust system is exhausting ambient air and inspecting system</td></tr>
<tr><td>6</td><td>Check with Facility Management before starting flow measurements to verify that the stack is not exhausting radioactive or other hazardous process exhaust. Only perform airflow measurements when an exhaust stack, duct, or vent is exhausting ambient air from a laboratory or facility.</td></tr>
</table>

Steps continued on next page.

Measuring flow, continued

Step	Action
7	Before measuring the airflow, inspect the exhaust system, i.e. fan(s), dampers, etc. Record, in section 2 of the Velocity Measurement Input Form, any unusual conditions or variations observed in the configuration of the exhaust system during the inspection. Report these findings to the Facility Management Unit and determine if the FM will allow the work to proceed under the conditions.
Setting up and adjusting equipment	
8	Before connecting the EDM to the tubing, verify that the EDM "zeros" when the ports are opened to the atmosphere. If the EDM does not "zero," record the Δp offset. If the Δp offset is greater than 0.01, DO NOT USE; replace the EDM or recalibrate it.
9	Connect the manometer to the pitot tube using capillary tubing in the manner described in the manufacturer's instructions. Record a check in the appropriate box in section 3 of the Velocity Measurement Input Form.
10	Optional but recommended: Perform a pre-measurement leak check on the capillary tubing installed between the EDM and the pitot tube. The capillary tubing must be air tight, holding a pressure of 3 inches of H_2O for 15 seconds. **Do Not Pressurize The Tube By Mouth!** 1. Blow (or pump) dry air into the impact opening (the tip) until at least 3 inches of pressure registers on the EDM. Close off the tube. The pressure reading should remain stable for at least 15 seconds. 2. Next, pull a 3 inch vacuum to test the static pressure side. Again, the negative pressure reading should remain stable for at least 15 seconds after the tube is closed. Record a check in the appropriate box in section 3 of the Velocity Measurement Input Form (Form 5-M). If the system does not pass the leak test, correct the problem before performing flow measurements.
11	Adjust the EDM sensitivity to the gage setting recommended by the manufacturer for the velocity pressure anticipated (from past measurements). Record a check in the appropriate box in section 3 of the Velocity Measurement Input Form (Form 5-M).
12	Check to ensure the EDM zeros. Because the EDM reading and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse. Record a check in the appropriate box in section 3 of the Velocity Measurement Input Form.

Steps continued on next page.

Measuring flow, continued

Step	Action
Performing traverse readings	
13	Record the time of the first reading in section 4 of the Velocity Measurement Input Form (Form 5-M).
14	Remove the measurement hole plugs as each hole is used and insert the pitot tube.
15	Seal the opening between the stack wall and the pitot tube.
16	Verify with a level and square that the pitot tube is parallel to the cross-sectional plane of the stack and that the tube tip is parallel to the centerline of the stack before recording each velocity pressure reading. **IMPORTANT: The pitot tube MUST be level and the tip MUST be parallel to the centerline of the stack to insure accurate measurement of the velocity pressure.**
17	Measure the velocity pressures and temperature at the traverse points specified by MAQ (determined by MAQ by using EPA Reference Method 1 or 1A). Record the results on the appropriate Velocity Measurement Input Form (in Attachment 5, 6 or 7). Because the EDM display readings are not always stable, record the high and low readings observed on the EDM display at each traverse measurement; the low reading to the left, the high reading to the right. Record the average velocity pressure observed and the measured temperature at each traverse point. Reinsert the hole plug after each traverse has been completed. **NOTE**: Ensure that the proper EDM scale is being used for the range of VP values encountered. If it is necessary to change to a more sensitive gage, do so, and re-measure the VP and temperature readings at each traverse point.

Steps continued on next page.

Measuring flow, continued

Step	Action
18	Perform a post-test leak check on the capillary tubing installed between the EDM and the pitot tube. The capillary tubing must be air tight, holding a pressure of 3 inches of H_2O for 15 seconds. **Do Not Pressurize The Tube By Mouth!** • Blow (or pump) dry air into the impact opening (the tip) until at least 3 inches of water pressure registers on the EDM. Close off the tube. The pressure reading should remain stable for at least 15 seconds. • Next, pull a 3 inch vacuum to test the static pressure side. Again, the negative pressure reading should remain stable for at least 15 seconds after the tube is closed. Record a check in the appropriate box in section 6 of the Velocity Measurement Input Form (Form 5-M). If the system does not pass the leak test, void the measurement. Correct and document the problem and repeat the flow measurements.
19	Measure the static pressure in the stack. One reading at the approximate center of the stack is usually sufficient. Record the measurement in section 7 of the Velocity Measurement Input Form (Form 5-M).
20	Determine the moisture content of the exhaust air by using a hand held relative humidity meter. Record the relative humidity reading in section 7 of the Velocity Measurement Input Form (Form 5-M).
21	Before plugging the last hole, the standard pitot tube (this step not required for Type-S pitot tube) must be cleared and tested to validate the velocity pressure readings. Use a can of compressed air to 'back-purge' the pitot tube. Reconnect the capillary tubing and position the pitot tube at the location of the last traverse measurement taken. Take the velocity pressure verification reading and record the location and velocity pressure reading in section 8 of the Velocity Measurement Input Form (Form 5-M). The stack readings are valid if the verification reading is within 5% of the last traverse reading. **NOTE**: If the last air flow measurement appears unstable or unsuitably low because of the proximity to the stack wall, then another air flow measurement from another location must be verified. If the readings are not validated, void the log entries and repeat the measurement.

Steps continued on next page.

Measuring flow, continued

Step	Action
Completing measurements	
22	Determine the stack gas dry molecular weight. For processes emitting essentially air, use a dry molecular weight of 29.0. Record the gas dry molecular weight in section 9 of the Velocity Measurement Input Form (Form 5-M). EXCEPTION: For combustion processes or processes that emit essentially CO_2, O_2, CO, and N_2, use EPA Reference Method 3 to determine the stack gas dry molecular weight. EPA Reference Method 3 is not covered in this procedure.
23	Record, in section 10 of the Velocity Measurement Input Form (Form 5-M), any condition(s) that may affect the accuracy or the validity of the measurement data. For example, erratic readings, parallel and perpendicular to flow, etc.
24	Plug the last hole. Record a check in the box in section 11 of the Velocity Measurement Input Form.
25	Record the time of the last reading in section 4 of the Velocity Measurement Input Form (Form 5-M).
26	Inspect the work site to be sure all equipment and tools have been collected.
27	Determine the atmospheric pressure from either JCNNM's barometer or MAQ's meteorology's barometer located at TA-06 for the time that the airflow in each stack was measured. Record the reading and the barometer used in section 12 of the Velocity Measurement Input Form (Form 5-M).

Steps continued on next page.

Measuring flow, continued

Step	Action
Performing post measurement verifications	
28	If a manometer (EDM) other than an oil-gage manometer was used, then a post measurement verification must be performed. Verify the accuracy of the reading on the EDM against another calibrated manometer (or an oil-gage manometer). The readings should not deviate more than 5% above or below the instrument that was used in the field. Record the test results in section 13 of the Velocity Measurement Input Form. **NOTE**: The readings must be verified in a wind tunnel at three different air velocities representing the approximate range of velocity pressure readings (high-mid-low) to be encountered in the field. If the measured stack velocity is in excess of 3,500 ft./minute, the velocity pressure readings must be verified in the field using a second EDM. The velocity readings measured at each point must not vary by more than 5%. Use the historical air velocity measurements for the appropriate stack(s) to determine the velocity range. **Isolated Pitot Tubes --** After each field use, the pitot tube must be carefully re-examined in top, side, and end views. If the pitot face openings are still aligned within the specifications illustrated in Attachment 1, EPA Figure 2-2 or 2-3, assume that the baseline coefficient of the pitot tube has not changed. If the tube has been damaged to the extent that it no longer meets the specifications of the EPA Figure 2-2 or 2-3, the damage must either be repaired to restore proper alignment of the face openings, or the tube must be discarded. **Pitot Tube Assemblies --** After each field use, check the face opening alignment of the pitot tube as in Type-S Pitot Tube Equipment Form (Form 1). Re-measure the inter-component spacing of the assembly. If the inter-component spacing has not changed and the face opening alignment is acceptable, assume that the coefficient of the assembly has not changed. If the face opening alignment is no longer within the specifications of Attachment 1, EPA Figure 2-2 or 2-3, repair the damage or replace the pitot tube (calibrating the new assembly, if necessary). If the inter-component spacing has changed, restore the original spacing, or re-calibrate the assembly.

Steps continued on next page.

Measuring flow, continued

Completing and submitting forms	
29	Verify the accuracy of the digital thermometer reading against a calibrated mercury-in-glass thermometer at ambient temperature. The temperatures, in degrees Rankine, should not deviate more than 1.5%. Record the verification information in section 13 of the Velocity Measurement Input Form. (°R = °F + 460)
30	Complete, sign, and forward the forms to MAQ for the calculation and verification of the air velocity and flow rate. If the original data are transcribed, attach the original data sheet to the transcribed copy and submit both copies. Perform a 100% independent verification on the transcribed data to insure no errors have been performed. Document the review of the data by checking column 1 and signing Attachment 8 (“Stack Flow Data Transcription and Entry Verification Form”).

Equipment calibration records

Submit the following to MAQ:

- by January 10th, an annual listing of all equipment used to support the flow measurement program;
- within two weeks of purchasing a new type-S pitot tube, a copy of the “Type-S Pitot Tube Equipment Form” in Attachment 2 for each Type-S pitot tube used;
- in the monthly deliverable, a copy of the calibration certificate for any equipment calibrated or purchased during the month;
- all original calibration certificates and any manufacturer’s documentation for all program equipment, when removed from service or disposed of.

Performing calculations

Verify data collection

MAQ personnel will inspect the data package to ensure all appropriate documentation has been included. This includes verifying that the appropriate data has been properly recorded, values are within the expected range for that parameter, and JCNNM personnel have performed all QA requirements.

Performing calculations

MAQ personnel will input the collected data into the Access database "Stacks" which will perform the flow measurement calculations. Perform a 100% independent verification on the data entered into the "Stacks" database to insure no errors have been performed. Document the review of the data by checking column 2 and signing Attachment 8 ("Stack Flow Data Transcription and Entry Verification Form").

If the computer program is not available, or as a check on the program, an **MAQ Mechanical Engineer** (or other qualified individual) performs flow measurement calculations manually by following the steps below and using the Flow Measurement Calculation Form (Form 6) to document the results. Carry out calculations retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation. After calculation, enter the data into the MAQ "Stacks" database.

Calculation nomenclature

The following terms are used in flow measurement calculations:

A = Cross-sectional area of the stack or duct, ft^2.
B_{ws} = Water vapor in the gas stream (from Method 5 or Reference Method 4), proportion by volume. Use a value of 0% relative humidity for conservatism.
C_p = Pitot tube coefficient, dimensionless.
K_p = Pitot tube constant,

$$85.49 \frac{ft}{sec} \left[\frac{lb/\ lb\text{-}mole)\ (in.Hg)}{(°R)\ (in.H_2O)} \right]^{1/2}$$

M_d = Molecular weight of stack gas, dry basis, lb/lb-mole.
M_s = Molecular weight of stack gas, wet basis, lb/lb-mole.

$$= M_d (1 - B_{ws}) + 18.0 B_{ws} \quad \text{Note: } (B_{ws} = 0)$$

P_{bar} = Barometric pressure at measurement site, in. Hg.
P_g = Stack static pressure, in. Hg.
P_{ref} = Barometric pressure at reference barometer, inches Hg.
P_s = Absolute stack pressure, in. Hg,

$$P_s = P_{bar} + P_g$$

Performing calculations, continued

Calculation nomenclature, *continued*

P_{std} = Standard absolute pressure, 29.92 in. Hg.
Q_{sd} = Dry volumetric stack gas flow rate corrected to standard conditions, dscf/hr.
t_s = Stack temperature, °F.
T_s = Absolute stack temperature, °R.

$$°R = 460 + t_s$$

T_{std} = Standard absolute temperature, 528°R.
v_s = Average stack gas velocity, ft/min.
Δp = Velocity head of stack gas, in. $H_2 0$.
3,600 = Conversion factor, sec/hr.
18.0 = Molecular weight of water, lb/lb-mole.

Steps to perform calculations

To perform flow measurement calculations, perform the following steps:

Step	Action
1	From the field input form, calculate the average stack gas temperature. The average stack gas temperature is: $$t_{s(avg)} = \frac{\sum_{i=1}^{n} t_i}{n}$$ where "n" is the number of measurement points. The exhaust stack average absolute temperature is: $$T_{s(avg)} = 460 + t_{s(avg)} \quad \text{for English}$$
2	The exhaust stack absolute pressure is given by: $$P_s = P_{bar} + P_g \quad \text{inches Hg}$$ where, corrected for elevation, the barometric pressure at the measurement site is: $$P_{bar} = P_{ref} + \left(Elevation_{profile} - Elevation_{ref}\right)\left(\frac{-0.1'' Hg}{100 ft}\right) \quad \text{inches Hg}$$ and the stack gas pressure (static pressure) is $$P_g = P_g'' wg\left(\frac{62.4}{846.9}\right) \quad \text{inches Hg}$$

Steps continued on next page.

Performing calculations, continued

Step	Action
3	The molecular weight of the gas, wet basis, is given by: $M_s = M_d(1 - B_{ws}) + 18.0 B_{ws}$ **Note**: ($B_{ws} = 0$) Assuming relatively dry air, the molecular weight of the gas, wet basis, reduces to the molecular weight of the stack gas, dry basis, which is: M_d = Molecular weight of stack gas, dry basis, lb/lb-mole. For processing <u>emitting essentially dry air</u>, use: $M_s = M_d = 29.0$ lb/lb-mole
4	Determine K from the following: $K = K_p \left(\frac{60 \sec}{\min}\right) \sqrt{\frac{T_{s(avg)}}{P_s M_s}}$ where $K_p = 85.49 \frac{ft}{sec} \left[\frac{(lb/\,lb\text{-}mole)\ (in.Hg)}{(°R)\ (in.H_2O)}\right]^{1/2}$
5	From the field input form, calculate the average velocity head of the stack gas. The average velocity head is: $(\sqrt{\Delta p})_{(avg)} = \frac{\sum_{i=1}^{n} \sqrt{\Delta p}}{n}$
6	Calculate the average stack gas velocity (actual): $v_s = C_p K (\sqrt{\Delta p})_{avg}$ ft/min
7	Calculate the exhaust stack flow rate (actual): $Q_{sd} = v_s A$ acfm
8	Calculate the average stack gas dry volumetric flow rate: $Q_{sd} = (1 - B_{ws}) v_s A \frac{T_{std}}{T_{s(avg)}} \frac{P_s}{P_{std}}$ scfm

Performing calculations, continued

Reviewing calculations

An **MAQ QA reviewer** reviews the data package to verify all parameters have been entered correctly. The **QA reviewer** also verifies that the "Stacks" database printout accurately reflects the data forms. The **QA reviewer** documents the review by initialing the forms and signing the bottom of the "Stacks" output and forwards the final data package to the MAQ Engineer.

Reviewing and verifying calculations

Review and verify calculations	The **MAQ engineer** receives the original data forms, final velocity and volumetric flow rate calculations, and all supporting documentation and performs a detailed review and verification. Initial the forms to indicate approval of data and calculation results.
Submit records	The **MAQ engineer** forwards the forms to the MAQ Records Center.
Update the database	The **MAQ engineer** updates the STACKS database when any changes occur to the stack flow measurement equipment or the ventilation system (e.g., calibration, new equipment, stack diameter, measurement matrix, etc.).

Records resulting from this procedure

Records

The following records generated as a result of this procedure are to be submitted as records **within two weeks of MAQ acceptance** to the group records coordinator:

- Attachment 4, Velocity Measurement Input Form (Form 5-M)
- Attachment 9 [Flow Measurement Calculation Form (Form 6)] or computer output of flow measurement calculations
- At least one of the following forms, as appropriate:
  - Attachment 5 [Velocity Measurement Input Form (2 x 12 Round Stack or Duct) (Form 5-R)]
  - Attachment 6 [Velocity Measurement Input Form (6 x 5 Rectangular Stack or Duct) (Form 5-S)]
  - Attachment 7 [Velocity Measurement Input Continuation Form (Form 5-C)]
- Attachment 2 [Type-S Pitot Tube Equipment Form (Form 1)] (when a pitot tube is checked or calibrated)
- Attachment 3 [Type-S Pitot Tube Calibration Worksheet (Form 3)] (when a pitot tube is calibrated)
- Attachment 8 (Stack Flow Data Transcription and Entry Verification Form)
- One of the following forms, when a new measurement location is selected:
  - Attachment 10 [Cross-Sectional Area Worksheet (Round Exhaust Stack/Duct) (Form 7-R)]
  - Attachment 11 [Cross-Sectional Area Worksheet (Rectangular Exhaust Stack/Duct) (Form 7-S)]

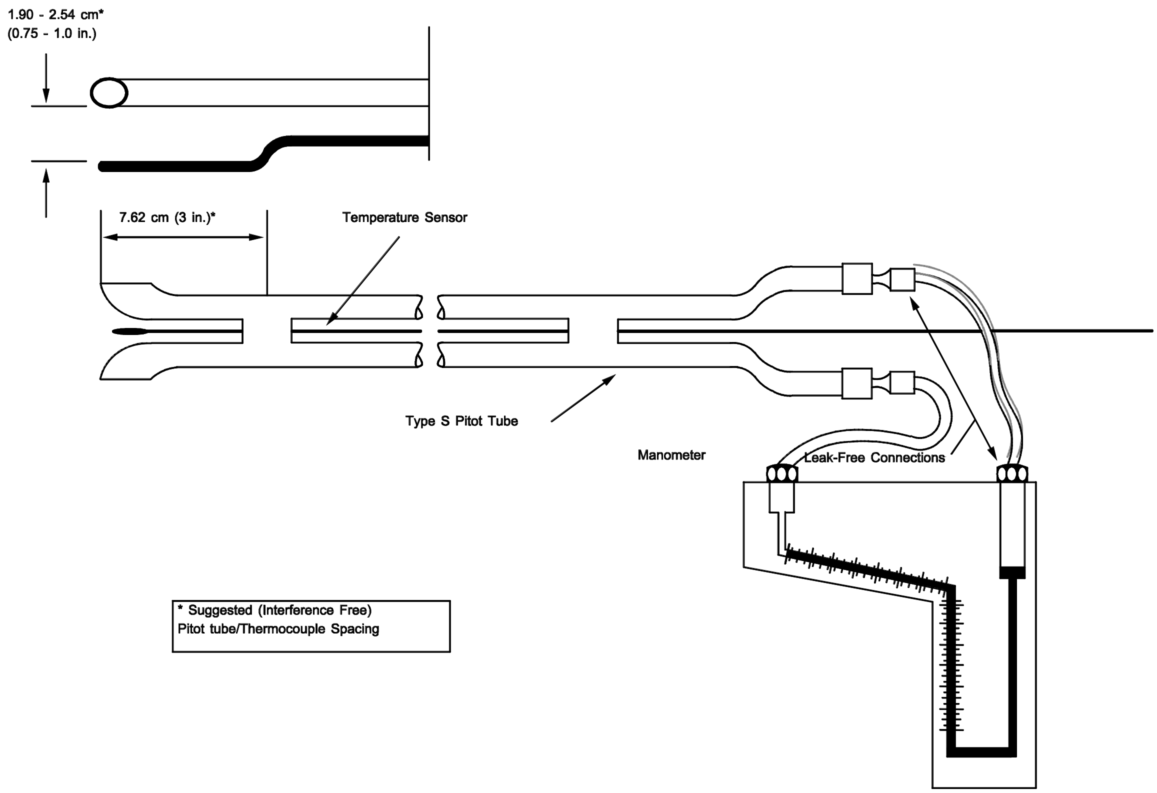
Work order documents maintained by JCNNM

Record files must be established and maintained by JCNNM to support the MAQ Rad-NESHAP project flow measurement program.

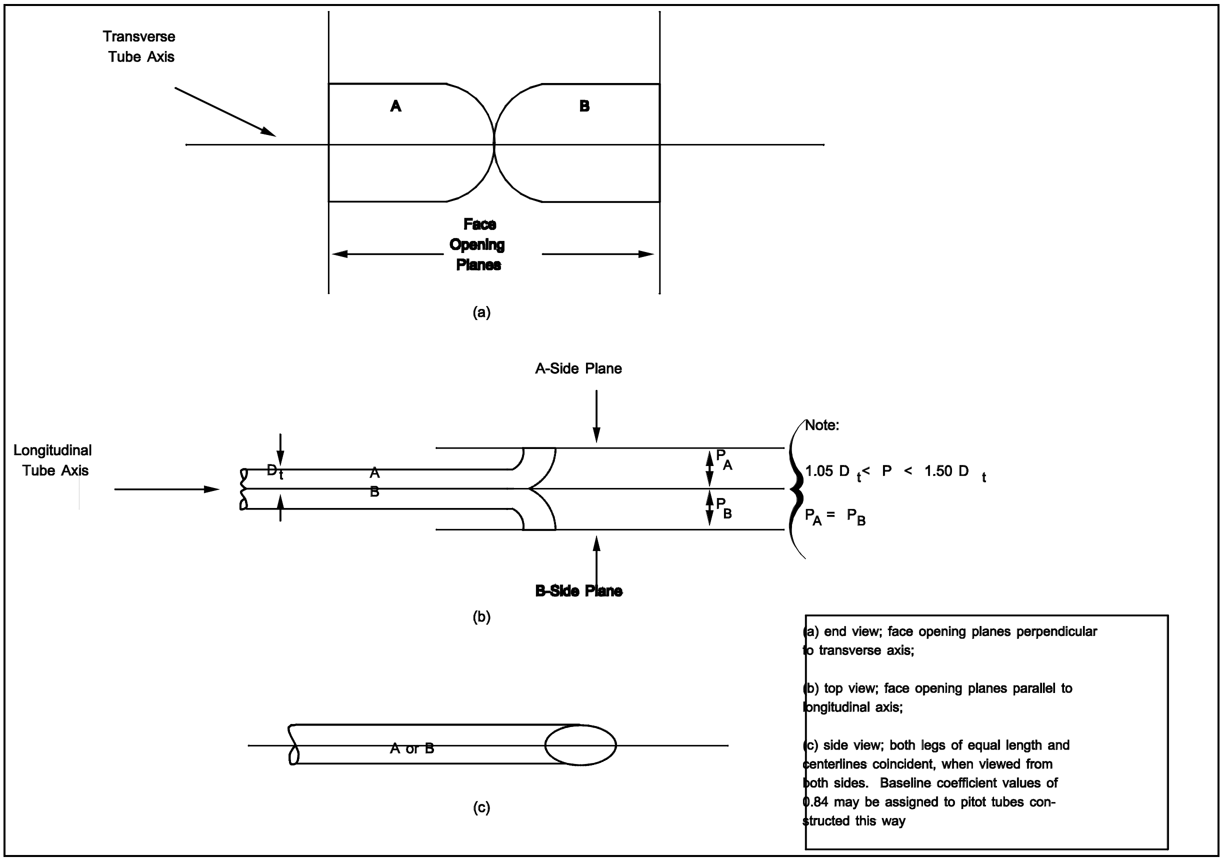
Work records must be maintained by JCNNM. Records to be filed and maintained in shop files for a minimum of two years include, as a minimum, copies of the following documentation.

- hazard analysis (e.g., AHA)
- ESH reviews

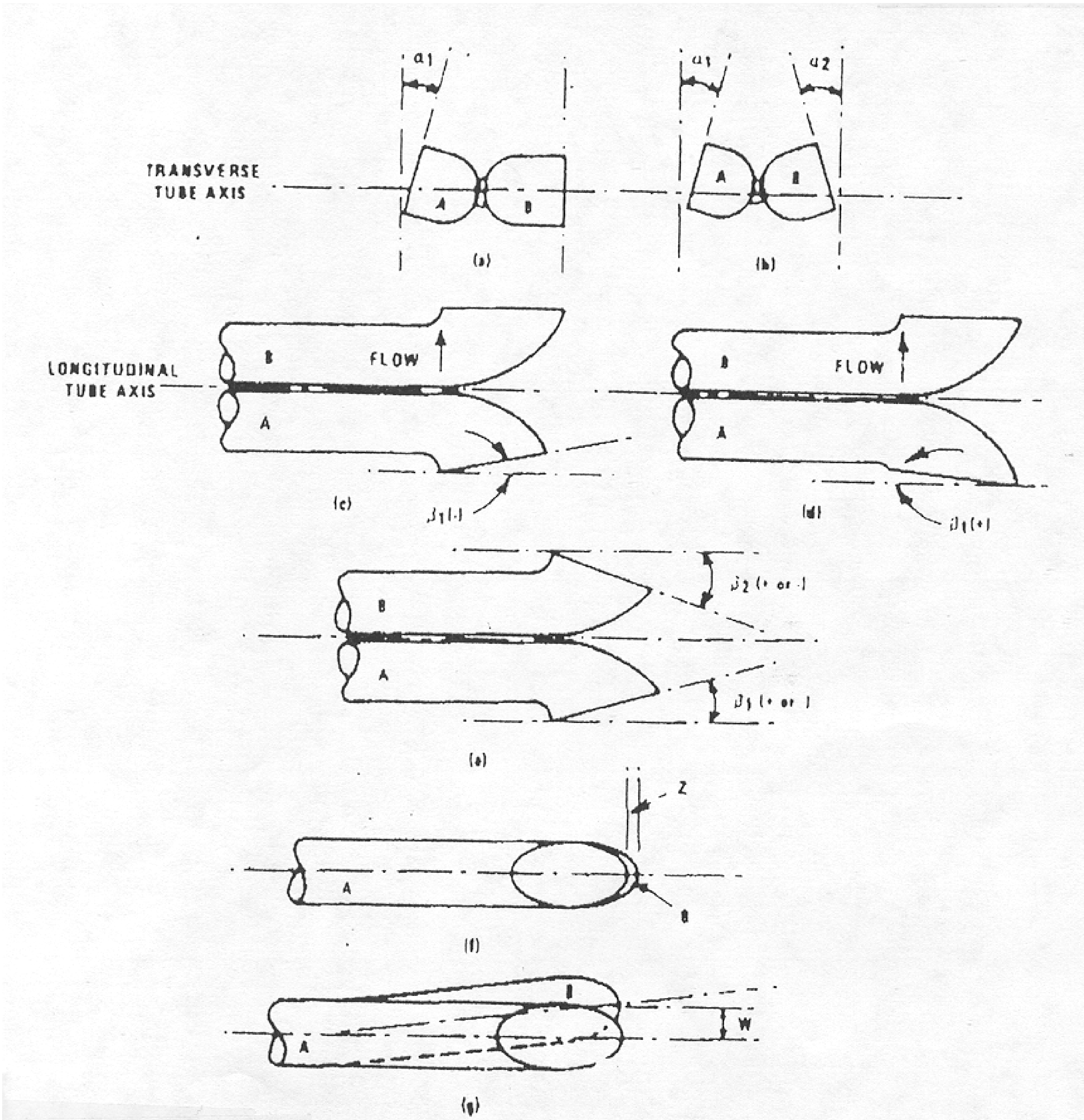
EPA Reference Methods Diagrams



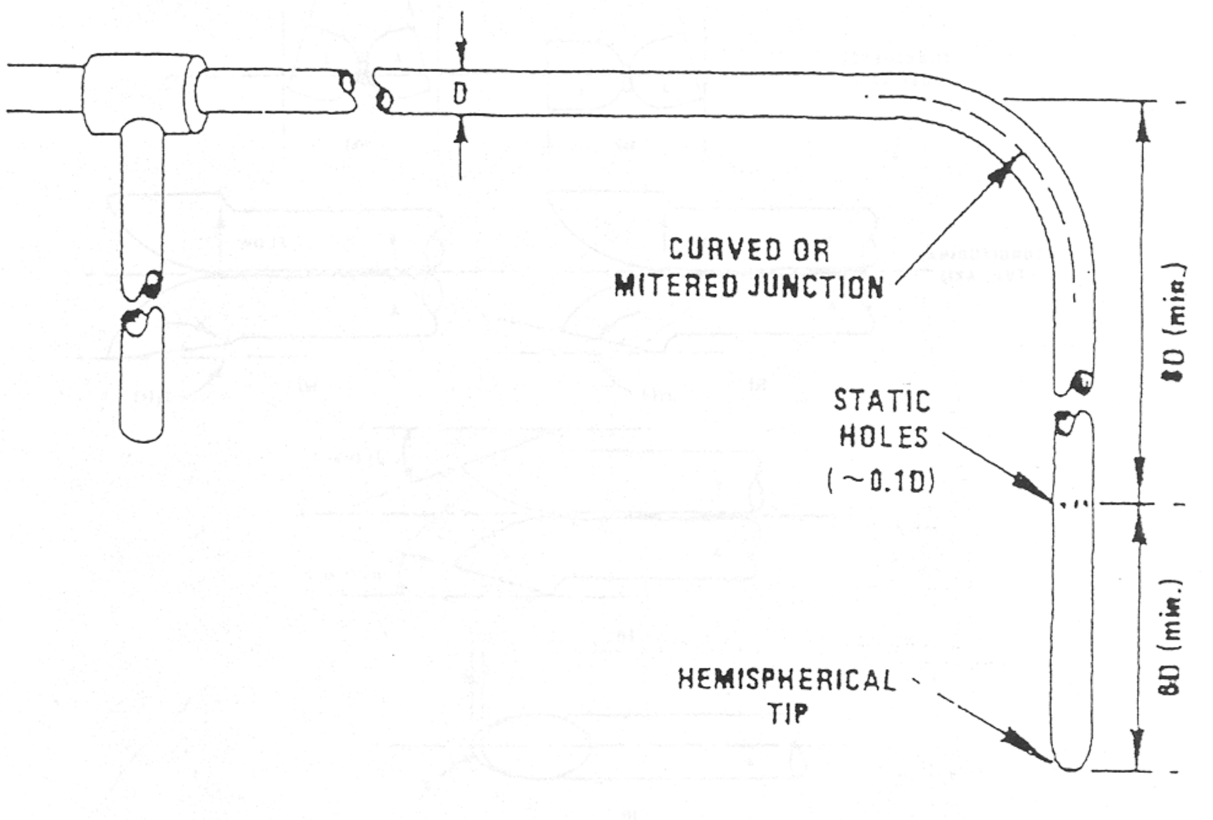
EPA Figure 2-1. Type S pitot tube manometer assembly.



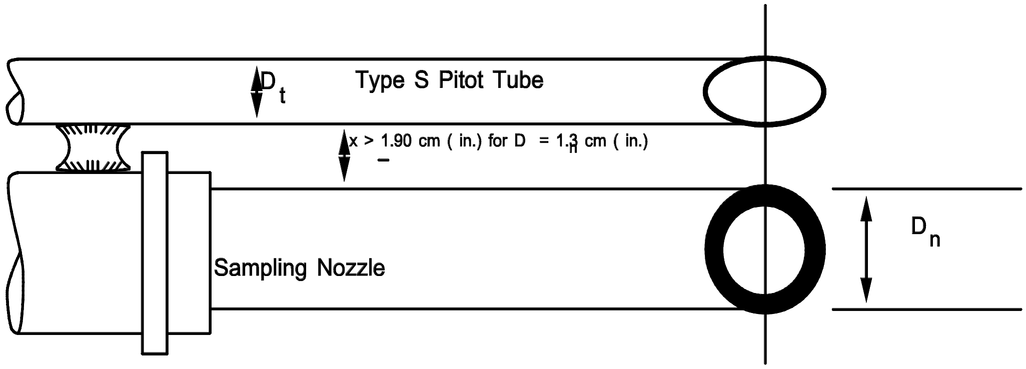
EPA Figure 2-2. Properly constructed Type S pitot tube.



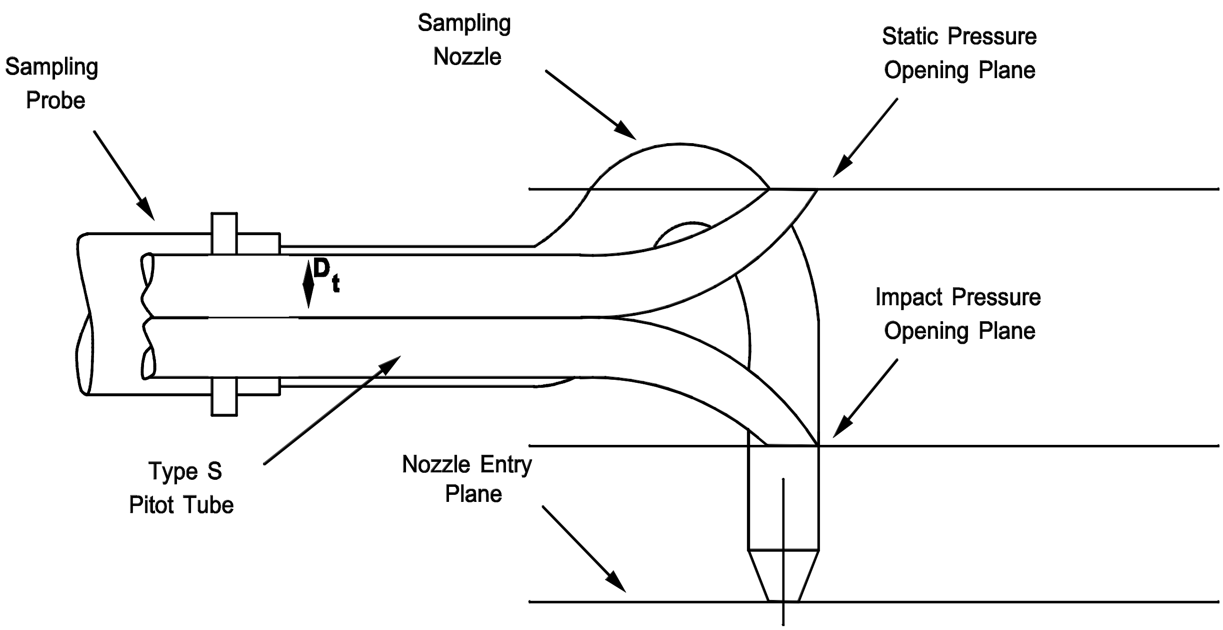
EPA Figure 2-3. Types of face-opening misalignment that can result from field use or improper construction of Type S pitot tubes. These will not affect the baseline value of Cp(s) so long as a^1 and a^2 £10°, b^1 and b^2 £5°, z £0.32 cm (1/8 in.) and w £0.08 cm (1/32 in.) (citation 11 in Bibliography).



EPA Figure 2-4. Standard pitot tube design specifications.

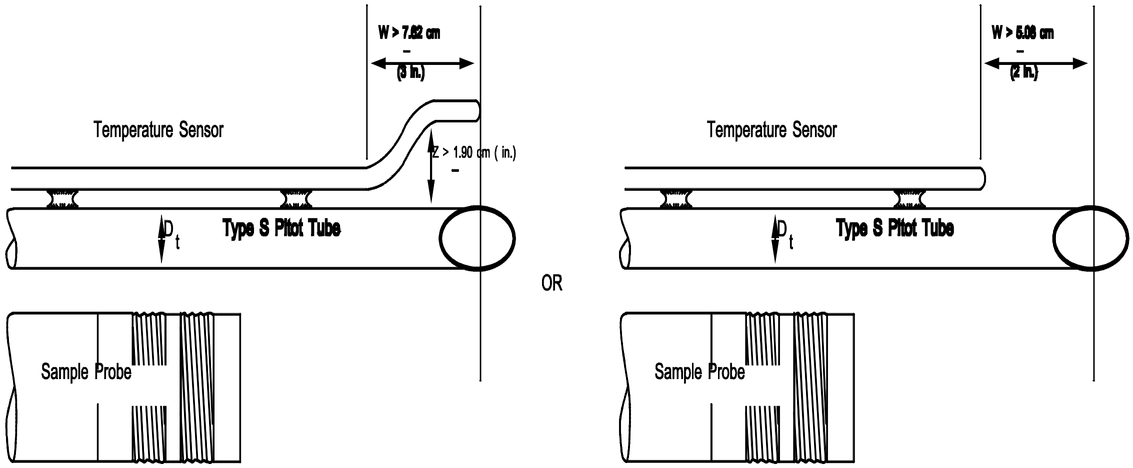


A. Bottom View; showing minimum pitot tube-nozzle separation.

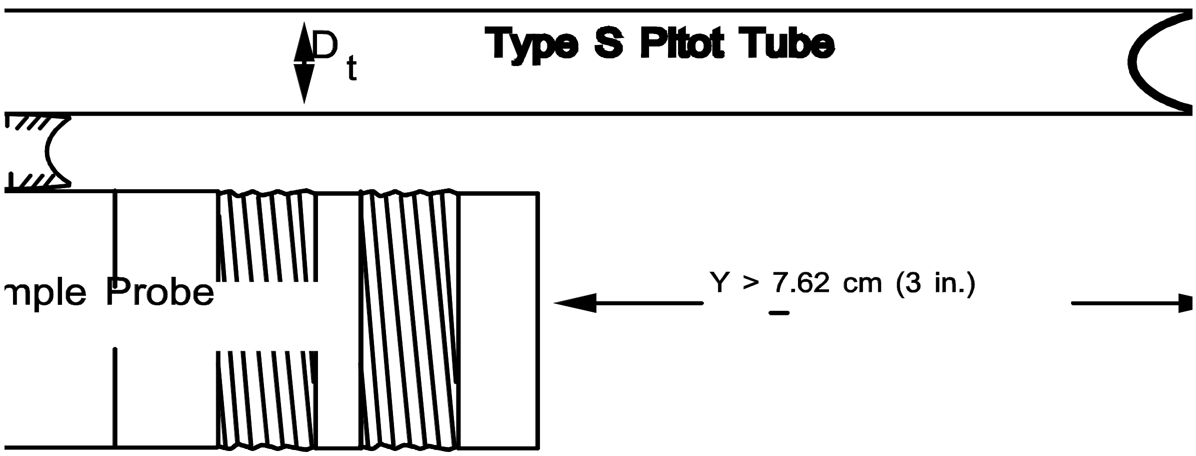


B. Side View; to prevent pitot tube from interfering with gas flow streamlines approaching the nozzle, the impact pressure opening plane of the pitot tube shall be even with or above the nozzle entry plane.

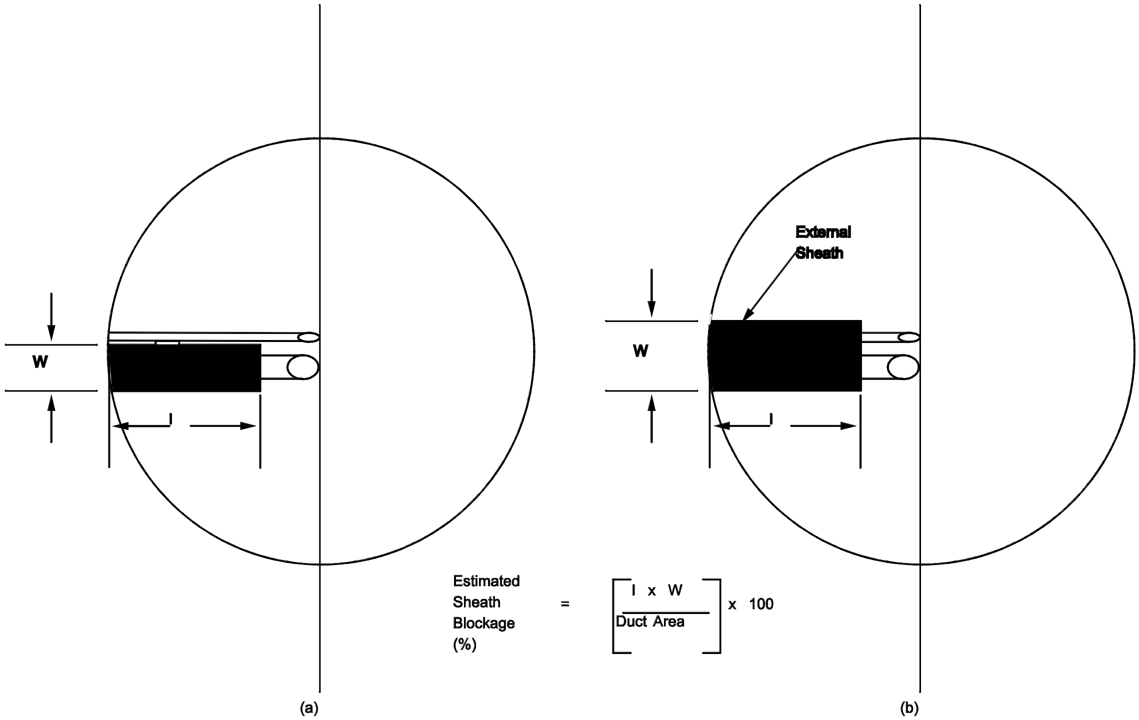
EPA Figure 2-6. Proper pitot tube-sampling nozzle configuration to prevent aerodynamic interference; button-hook type nozzle; centers of nozzle and pitot opening aligned; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).



EPA Figure 2.7. Proper thermocouple placement to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).



EPA Figure 2-8. Minimum pitot-sample probe separation needed to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).



EPA Figure 2-10. Projected-area models for typical pitot tube assemblies.

Meteorology and Air Quality

Type-S Pitot Tube Equipment Form (Form 1)

Page 1 of 2 This form is from MAQ-127

Pitot Tube ID Number: ____________________________ (permanently marked on pitot tube)

Length of Pitot Tube: _______________ inches

1. Pitot Tube Face Opening Alignment:

End View ☐ Face opening planes perpendicular to transverse axis

☐ Face opening planes <u>not</u> perpendicular to traverse axis

α_1 = __________ degrees

α_2 = __________ degrees

☐ Acceptable if α_1 and $\alpha_2 \leq 10°$

☐ Option 2 or do not use pitot tube

Top View ☐ Face opening planes parallel to longitudinal axis

☐ Face opening planes <u>not</u> parallel to longitudinal axis

β_1 = __________ degrees

β_2 = __________ degrees

☐ Acceptable if β_1 and $\beta_2 \leq 5°$

☐ Option 2 or do not use pitot tube

Side View ☐ Both legs of equal length and centerlines coincident, when viewed from both sides.

☐ Both legs <u>not</u> of equal length and centerlines <u>not</u> coincident, when viewed from both sides.

z = __________ inches

w = __________ inches

☐ Acceptable if z ≤ 1/8 inch and w ≤ 1/32 inch

☐ Option 2 or do not use pitot tube

Meteorology and Air Quality

Type-S Pitot Tube Equipment Form (Form 1), continued

This form is from MAQ-127

2. Measure Pitot Tube Dimensions:

External tubing diameter D_t = __________ inches

Base-to-Opening plane distances P_A = __________ inches

P_B = __________ inches

3. Compare Measured Dimensions

If [P_A] __________ = __________ [P_B]

and 3/16 inch ≤ [D_t] __________ ≤ 3/8 inch

and [illegible] D_t [illegible] $P_{(A\ and\ B}$ [illegible] .50 D_t [illegible] D_t __________

[illegible] $_t$ = __________

[illegible] $_t$] __________ < [illegible] $_{(A\ and\ B)}$ __________ < [1.50 [illegible] __________

then ☐ use Option 1 (unless pitot tube is part of an assembly) or Option 2

otherwise, ☐ use Option 2

4. Pitot Tube Coefficient Options

☐ Option 1: If the tube is isolated (e.g., not part of an assembly), then you may assign a baseline coefficient of 0.84 .

Pitot Tube Coefficient 0.84

☐ Option 2: Calibrate the pitot tube according to the procedure outlined in Attachment x3. This option must be used if the pitot tube is part of an assembly.

Pitot Tube Coefficient A Side _____

B Side _____

Comments

____

Measurements performed by:

Signature	Print name	Z-Number	Date
____________	________________	__________	____/____/____

QA check by:

Signature	Print name	Z-Number	Date
____________	________________	__________	____/____/____

MAQ review and approval by:

Signature	Print name	Z-Number	Date
____________	________________	__________	____/____/____

Meteorology and Air Quality

Type-S Pitot Tube Calibration Worksheet (Form 3)

This form is from MAQ-127

Pitot Tube ID Number: ____________________ Date Calibrated: _____/_____/_____

	"A" SIDE CALIBRATION			
RUN NO.	VP_{std} in H_2O	$VP_{(s)}$ in H_2O	$C_{p(s)}$	Deviation $C_{p(s)} - C_p(A)$
1				
2				
3				
		$C_{p,avg}$ (SIDE A)		

	"B" SIDE CALIBRATION			
RUN NO.	VP_{std} in H_2O	$VP_{(s)}$ in H_2O	$C_{p(s)}$	Deviation $C_{p(s)} - C_p(B)$
1				
2				
3				
		$C_{p,avg}$ (SIDE B)		

$$\text{AverageDeviation} = \sigma_{(\text{AorB})} = \frac{\sum_{i=1}^{3} \left| C_{p(s)} - \overline{C}_{p(\text{AorB})} \right|}{3} \rightarrow \text{MustBe} \leq 0.01$$

$$\left| \overline{C}_p(\text{SideA}) - \overline{C}_p(\text{SideB}) \right| \rightarrow \text{MustBe} \leq 0.01$$

Calculations by:

____________________ ____________________ ____________________ _____/_____/_____
Signature | Print name | Z-Number | Date

QA check by:

____________________ ____________________ ____________________ _____/_____/_____
Signature | Print name | Z-Number | Date

MAQ review and approval by:

____________________ ____________________ ____________________ _____/_____/_____
Signature | Print name | Z-Number | Date

Meteorology and Air Quality

Velocity Measurement Input Form (Form 5-M)

Page 1 of 2 This form is from MAQ-127

TA/Building/ES ______-______-______ FE(s) ____

Measurement Date _____/_____/_____ PM #: ____

Profile Measurement Number __________ Fan Exhaust Configuration __________

☐ Quarterly airflow measurement ☐ Special Measurement ☐ Other:____________________

☐ Method 2 (stack or duct diameter ≥ 12 inches) or ☐ Method 2C (stack or duct diameter ≥ 4 inches but < 12 inches)

1. Equipment used and verification

Manometer _____________ Serial Number _____________ Calibration Expiration ____/____/____

Thermometer _____________ Serial Number _____________ Calibration Expiration ____/____/____

Humidity Meter _____________ Serial Number _____________ Calibration Expiration ____/____/____

Pitot Tube _____________ Serial Number _____________

☐ Traverse spacing pre-marked on pitot tube / pitot tube inspected

2. Location inspection

Location Comments: ____

3. Equipment setup

☐ Zero the manometer •P offset ____________

☐ Connect manometer to tubing ☐ Adjust manometer sensitivity

Pre-test leak check performed (not mandatory): ☐ Yes ☐ No

4. Perform traverse readings (record velocity pressure and temperature in table on appropriate form)

Run Start Time:___________ Run Complete Time:___________ Average Temperature____________

5. Diameter and cross-sectional area of stack or duct (from previous measurements)

Diameter: ____________ (in.) Dimensions: ________________ (in.) Area: ______________ (sq feet)

6. Post measurement leak test (3" wg)

☐ successful ☐ measurement voided

7. Static Pressure and Relative Humidity

SP=_____________ (" H_2O) RH=______________%

8. Back purge standard pitot tube and verify ☐ Not required

Profile location ____________ Reading _________ (in wg) Percent difference ________ %

Meteorology and Air Quality

Velocity Measurement Input Form (Form 5-M), continued

Page 2 of 2

This form is from MAQ-127

9. Stack gas dry molecular weight

☐ Reference Method 3 ___________ ☐ Room Air (Use 29.0)

10. Condition which might affect measurements

____

11. Holes covered

☐ Complete

12. Atmospheric Pressure

____________ ("Hg) Barometer Location ______________________

13. Post Measurement Verifications

☐ Manometer verification passed (within 5%) ☐ Manometer verification not required.

Test Number	Velocity Pressure (inches w.c.)		
	Manometer	Reference	% Difference
1			
2			
3			

☐ Thermometer verification passed (within 1.5%)

Temperature Reading °F		Absolute Temperature °R		
		°R = °F + 460		
Thermometer	Reference	Thermometer	Reference	% Difference

Comments:

Flow measurements were made in accordance with the latest revision of MAQ-127.
Measurements by:

Signature	Print name	Z-Number	Date ____/____/____

MAQ QA check by (initials):	MAQ review and approval by (initials):

Meteorology and Air Quality

Velocity Measurement Input Form (Form 5-R)

(2 x 12 Round Stack or Duct)

Page 1 of 1 This form is from MAQ-127

TA/Building/ES ______-______-______ Measurement Date _____/_____/_____

Measurement Traverse A				Measurement Traverse B			
Point	Spacing (nearest 1/8 in)	Velocity Pressure (in H_2O)	Temperature (°F)	Point	Spacing (nearest 1/8 in)	Velocity Pressure (in H_2O)	Temperature (°F)
A1				B1			
A2				B2			
A3				B3			
A4				B4			
A5				B5			
A6				B6			
A7				B7			
A8				B8			
A9				B9			
A10				B10			
A11				B11			
A12				B12			
CP-A				CP-B			

SAMPLE

Measurements by:

_____________________ _________________________ ________________ _____/_____/_____
Signature Print name Z-Number Date

MAQ QA check by (initials): MAQ review and approval by (initials):

Meteorology and Air Quality

Velocity Measurement Input Form (Form 5-S)

(6 x 5 Rectangular Stack or Duct)

Page 1 of 1

This form is from MAQ-127

TA/Building/ES ______-______-______ Measurement Date _____/_____/_____

Measurement Traverse A				Measurement Traverse B			
Point	Spacing (nearest 1/8 in)	Velocity Pressure (in H_2O)	Temperature (°F)	Point	Spacing (nearest 1/8 in)	Velocity Pressure (in H_2O)	Temperature (°F)
A1				D1			
A2				D2			
A3				D3			
A4				D4			
A5				D5			
B1				E1			
B2				E2			
B3				E3			
B4				E4			
B5				E5			
C1				F1			
C2				F2			
C3				F3			
C4				F4			
C5				F5			

Measurements by:

____________________ ____________________ ________________ _____/_____/_____
Signature Print name Z-Number Date

MAQ QA check by (initials):

MAQ review and approval by (initials):

Meteorology and Air Quality

Velocity Measurement Input Continuation Form (Form 5-C)

Page 1 of 1

This form is from MAQ-127

TA/Building/ES ______-______-______ Measurement Date _____/_____/_____

Measurement Traverse ____				Measurement Traverse ____			
Point	Spacing (nearest 1/8 in)	Velocity Pressure (in H_2O)	Temperature (°F)	Point	Spacing (nearest 1/8 in)	Velocity Pressure (in H_2O)	Temperature (°F)
CP				CP			

SAMPLE

Measurements by:

______________________ ____________________________ _________________ ______/______/______
Signature Print name Z-Number Date

MAQ QA check by (initials):

MAQ review and approval by (initials):

Meteorology and Air Quality

Stack Flow Data Transcription and Entry Verification Form

Page 1 of 1 This form is from MAQ-127

Place check in appropriate column:
Column 1: Data transcription verification **Column 2**: Data entry verification

1	2	Stack ID	1	2	Stack ID
		TA-03, bldg-0029, ES-14, config. # 02			TA-41, bldg-0004, ES-17, config. #01
		TA-03, bldg-0029, ES-15, config. # 01			TA-48, bldg-0001, ES-07, config. # 01
		TA-03, bldg-0029, ES-19, config. # 01			TA-48, bldg-0001, ES-07, config. # 02
		TA-03, bldg-0029, ES-20, config. # 01			TA-48, bldg-0001, ES-54, config. # 01
		TA-03, bldg-0029, ES-23, config. # 01			TA-48, bldg-0001, ES-60, config. # 01
		TA-03, bldg-0029, ES-24, config. # 01			TA-50, bldg-0001, ES-02, config. # 01
		TA-03, bldg-0029, ES-28, config. # 01			TA-50, bldg-0037, ES-01, config. # 01
		TA-03, bldg-0029, ES-29, config. # 01			TA-50, bldg-0069, ES-03, config. # 01
		TA-03, bldg-0029, ES-32, config. # 01			TA-53, bldg-0003, ES-03, config. #
		TA-03, bld[illegible]029, [illegible]S-33, [illegible]g. # 01			TA-[illegible] bl[illegible]0003, ES[illegible], config. #
		TA-03, bld[illegible]29, ES-37[illegible]g. # 0[illegible]			TA[illegible] bl[illegible]-0003, ES[illegible]g. #
		TA-03, bldg-002[illegible]ES-4[illegible] # [illegible]			TA-53, b[illegible]-0003, E[illegible]3, config. #
		TA-03, b[illegible]ES[illegible]5, conf[illegible] # [illegible]			TA-53, [illegible] E[illegible]ig. #
		TA-03, bldg-0029, ES-46, config. # 02			TA-53, bldg-0007, ES-02, config. #
		TA-03, bldg-0102, ES-22, config. # 01			TA-53, bldg-0007, ES-02, config. #
		TA-03, bldg-0141, ES-01, config. # 01			TA-53, bldg-0007, ES-02, config. #
		TA-03, bldg-0141, ES-01, config. # 02			TA-53, bldg-0007, ES-02, config. #
		TA-16, bldg-0205, ES-04, config. # 02			TA-53, bldg-0007, ES-02, config. #
		TA-21, bldg-0155, ES-05, config. # 01			TA-53, bldg-0007, ES-02, config. #
		TA-21, bldg-0209, ES-01, config. # 01			TA-55, bldg-0004, ES-15, config. # 01
		TA-33, bldg-0086, ES-06, config. # 01			TA-55, bldg-0004, ES-16, config. # 01
		TA-33, bldg-0086, ES-06, config. # 02			
		TA-33, bldg-0086, ES-06, config. # 03			

For the stacks checked above in **column 1**, I have performed a 100% verification to ensure the data have been **transcribed** correctly from the "raw" data forms to the "official" records form. The parameters verified are the duct static pressure, cross-sectional area of the duct/stack, atmospheric pressure, temperature of air in the stack, and the velocity pressure readings.

________________ ____________________ ____________ _____/_____/_____

Signature Print name Z-Number Date

For the stacks checked above in **column 2**, I have performed a 100% verification to ensure the **data entered** into the "Stack" database corresponds to the data collected in the field. The parameters verified are the duct static pressure, cross-sectional area of the duct/stack, atmospheric pressure, temperature of air in the stack, and the velocity pressure readings.

________________ ____________________ ____________ _____/_____/_____

Signature Print name Z-Number Date

Meteorology and Air Quality

Flow Measurement Calculation Form (Form 6)

Page 1 of 2 | This form is from MAQ-127

TA/Building/ES ______-______-______ FE(s) ________________________

Measurement Date _____/_____/_____ Fan Exhaust Configuration _________

Profile Measurement Number _________

Step 1: Calculate the stack gas average absolute temperature, $T_{s(avg)}$

a) From field input form, determine $t_{s(avg)}$ = _________ °F

b) Calculate the absolute temperature, $T_{s(avg)} = t_{s(avg)} + 460$ = ________ °R

Step 2: Calculate the exhaust stack absolute pressure, P_s

a) From the field input form, record the barometric reference pressure, P_{ref} = _________ " Hg

b) Adju[illegible] elevation[illegible]

[illegible] P_{ref} [illegible] [Eleva[illegible]file [illegible] atio[illegible]] [illegible] Hg[illegible]00 ft)

= ______ [illegible] ______ ft ______ ft] (-0.1/[illegible])

= _____________ "Hg

c) From the field input form, record the stack static pressure, P_g = __________ " wg

d) Convert the static pressure from inches w.g. to inches Hg

P_g = [P_g"wg] (62.4 / 846.9) "Hg

= __________ (62.4 / 846.9) "Hg

= __________ "Hg

e) Calculate the exhaust stack absolute pressure

$P_s = P_{bar} + P_g$

= ________ + ________ = ________ "Hg

Step 3: Calculate the molecular weight of the stack gas, M_s

a) From Method 4 or 5 B_{ws} = __________ (**Always** use 0 for conservatism)

b) From Method 3 M_d = __________ (Use 29 for air)

c) Calculate M_s $M_s = M_d (1 - B_{ws}) + 18.0\ B_{ws}$

= ________ (1 - ________) + 18.0 (________)

= ________ lb / lb mole

Meteorology and Air Quality

Flow Measurement Calculation Form (Form 6), continued

Step 4: Calculate K

a) K = (85.49) (60) SQRT[$T_{s(avg)}$ / $P_s M_s$]

= (85.49)(60) SQRT [________ / (________)(________)] = ____________

Step 5: From the field input form, calculate the average velocity head of the stack gas

a) $$(\sqrt{\Delta p})_{(avg)} = \frac{\sum_{i=1}^{n} \sqrt{\Delta p}}{n}$$ = __________ inches water

Step 6: Calculate the average stack gas velocity (actual), v_s

a) $C_p\ K\ (\sqrt{\Delta p})_{avg}$

= ________ * ________

= ________ ft/min

Step 7: Calculate the exhaust stack flow rate (actual), Q

a) Record the stack/duct cross-sectional area from profile measurements

A = __________ ft^2

b) Q = v_s * A

= ________ * ________

= ________ acfm

Step 8: Calculate the exhaust stack gas dry volumetric flow rate (standard), Qsd

a) $$Q_{sd} = (1 - B_{ws})\, v_s A \ \frac{T_{std}}{T_{s(avg)}} \ \frac{P_s}{P_{std}}$$

Q_{sd} = [1 - ________] * ________ * ________ [________ / ________] [________ / ________]

Q_{sd} = ____________ scfm

Calculations by:

____________________	___________________________	________________	_____/_____/_____
Signature	Print name	Z-Number	Date

MAQ QA check by (initials):	MAQ review and approval by (initials):

Meteorology and Air Quality

Cross-Sectional Area Worksheet (Round Exhaust Stack or Duct) (Form 7-R)

Page 1 of 1 — This form is from MAQ-127

TA/Building/ES ______-______-______ FE(s) ________________________

Profile Measurement Number __________

1. Sketch the exhaust stack or duct cross- section and label the traverses. Include any references in the sketch.

SAMPLE

2. Measure the diameters to the nearest 1/8 inch

Traverse Number	Measured Diameter (nearest 1/8")	Diameter (decimal format in inches)
d_1		
d_2		
d_3		
d_4		

Measurements by:

______________ ______________ ______________ ____/____/____
Signature Print name Z-Number Date

3. Calculate the cross- sectional area. Do not round d or π . Round final number to three decimal places.

Round: $Area = \pi\left[\frac{d}{2}\right]^2\left[\frac{1}{144}\right]$ **OR** Oval: $Area = \frac{\pi * d_1 * d_2}{576}$ Area = ________________ sq feet

Calculations by:

______________ ______________ ______________ ____/____/____
Signature Print name Z-Number Date

MAQ QA check by (initials):	MAQ review and approval by (initials):

Meteorology and Air Quality

Cross-Sectional Area Worksheet (Rectangular Exhaust Stack or Duct) (Form 7-S)

Page 1 of 1

This form is from MAQ-127

TA/Building/ES ______-______-______ FE(s) ________________________

Profile Measurement Number __________

1. Sketch the exhaust stack or duct cross- section and label the traverses. Include any references in the sketch.

SAMPLE

2. Measure the widths and depths to the nearest 1/8 inch

Traverse Number	Measured Diameter (nearest 1/8”)	Diameter (decimal format in inches)
Width 1 (W1)		
Width 2 (W2)		
Depth 1 (D1)		
Depth 2 (D2)		

Measurements by:

____________________ ____________________ ________________ _____/_____/_____
Signature Print name Z-Number Date

3. Calculate the cross- sectional area. Round final number to three decimal places.

$$Area = \left[\frac{W1 + W2}{2}\right]\left[\frac{D1 + D2}{2}\right]\left[\frac{1}{144}\right]$$ sq feet

Area = ________________ sq feet

Calculations Performed by:

____________________ ____________________ ________________ _____/_____/_____
Signature Print name Z-Number Date

MAQ QA check by (initials):

MAQ review and approval by (initials):

Type-S Pitot Tube Equipment Form (Form 1)

Pitot Tube ID Number: ______________________________ (permanently marked on pitot tube)

Length of Pitot Tube: ________________ inches

1. Pitot Tube Face Opening Alignment:

End View

☐ Face opening planes perpendicular to transverse axis

☐ Face opening planes not perpendicular to traverse axis

α_1 = ___________ degrees

α_2 = ___________ degrees

☐ Acceptable if α_1 and $\alpha_2 \leq 10°$

☐ Option 2 or do not use pitot tube

Top View

☐ Face opening planes parallel to longitudinal axis

☐ Face opening planes not parallel to longitudinal axis

β_1 = ___________ degrees

β_2 = ___________ degrees

☐ Acceptable if β_1 and $\beta_2 \leq 5°$

☐ Option 2 or do not use pitot tube

Side View

☐ Both legs of equal length and centerlines coincident, when viewed from both sides.

☐ Both legs not of equal length and centerlines not coincident, when viewed from both sides.

z = ___________ inches

w = ___________ inches

☐ Acceptable if $z \leq 1/8$ inch and $w \leq 1/32$ inch

☐ Option 2 or do not use pitot tube

Type-S Pitot Tube Equipment Form (Form 1), continued

This form is from MAQ-127

2. Measure Pitot Tube Dimensions:

External tubing diameter D_t = __________ inches

Base-to-Opening plane distances P_A = __________ inches

P_B = __________ inches

3. Compare Measured Dimensions

If [P_A] __________ = __________ [P_B]

and 3/16 inch ≤ [D_t] __________ ≤ 3/8 inch

and $1.05\ D_t < P_{(A\ and\ B)} < 1.50\ D_t$ $1.05\ D_t$ = __________

$1.50\ D_t$ = __________

[$1.05\ D_t$] __________ < [$P_{(A\ and\ B)}$] __________ < [$1.50\ D_t$] __________

then ☐ use Option 1 (unless pitot tube is part of an assembly) or Option 2

otherwise, ☐ use Option 2

4. Pitot Tube Coefficient Options

☐ Option 1: If the tube is isolated (e.g., not part of an assembly), then you may assign a baseline coefficient of 0.84 .

Pitot Tube Coefficient 0.84

☐ Option 2: Calibrate the pitot tube according to the procedure outlined in Attachment x3. This option must be used if the pitot tube is part of an assembly.

Pitot Tube Coefficient A Side _____

B Side _____

Comments

____

Measurements performed by:

____________	________________	__________	____/____/____
Signature	Print name	Z-Number	Date

MAQ QA check by (initials):	MAQ review and approval by (initials):

Type-S Pitot Tube Calibration Worksheet (Form 3)

Pitot Tube ID Number: ____________________ Date Calibrated: _____/_____/_____

	"A" SIDE CALIBRATION			
RUN NO.	VP_{std} in H_2O	$VP_{(s)}$ in H_2O	$C_{p(s)}$	Deviation $C_{p(s)} - C_p(A)$
1				
2				
3				
		$C_{p,avg}$ (SIDE A)		

	"B" SIDE CALIBRATION			
RUN NO.	P_{std} in H_2O	$P_{(s)}$ in H_2O	$C_{p(s)}$	Deviation $C_{p(s)} - C_p(B)$
1				
2				
3				
		$C_{p,avg}$ (SIDE B)		

$$\text{AverageDeviation} = \sigma_{(\text{AorB})} = \frac{\sum_{i=1}^{3} \left| C_{p(s)} - \overline{C}_{p(\text{AorB})} \right|}{3} \rightarrow \text{MustBe} \le 0.01$$

$$\left| \overline{C}_p(\text{SideA}) - \overline{C}_p(\text{SideB}) \right| \rightarrow \text{MustBe} \le 0.01$$

Calculations by:

______________________ ____________________________ _________________ _____/_____/_____
Signature Print name Z-Number Date

MAQ QA check by (initials):	MAQ review and approval by (initials):

Velocity Measurement Input Form (Form 5-M)

TA/Building/ES ______-______-______ FE(s) ________________________________

Measurement Date _____/_____/_____ PM #: ________________________________

Profile Measurement Number __________ Fan Exhaust Configuration __________

☐ Quarterly airflow measurement ☐ Special Measurement ☐ Other:____________________

☐ Method 2 (stack or duct diameter ≥ 12 inches) or ☐ Method 2C (stack or duct diameter ≥ 4 inches but < 12 inches)

1. Equipment used and verification

Manometer _____________ Serial Number _____________ Calibration Expiration ____/____/____

Thermometer ___________ Serial Number _____________ Calibration Expiration ____/____/____

Humidity Meter___________ Serial Number _____________ Calibration Expiration ____/____/____

Pitot Tube _____________ Serial Number _____________

☐ Traverse spacing pre-marked on pitot tube / pitot tube inspected

2. Location inspection

Location Comments: ____

3. Equipment setup

☐ Zero the manometer •P offset ____________

☐ Connect manometer to tubing ☐ Adjust manometer sensitivity

Pre-test leak check performed (not mandatory): ☐ Yes ☐ No

4. Perform traverse readings (record velocity pressure and temperature in table on appropriate form)

Run Start Time:___________ Run Complete Time:___________ Average Temperature____________

5. Diameter and cross-sectional area of stack or duct (from previous measurements)

Diameter: ____________ (in.) Dimensions: ____________________ (in.) Area: ______________ (sq feet)

6. Post measurement leak test (3” wg)

☐ successful ☐ measurement voided

7. Static Pressure and Relative Humidity

SP=_____________ (” H_2O) RH=_______________%

8. Back purge standard pitot tube and verify ☐ Not required

Profile location _____________ Reading __________ (in wg) Percent difference _________ %

Velocity Measurement Input Form (Form 5-M), continued

This form is from MAQ-127

9. Stack gas dry molecular weight

☐ Reference Method 3 ________ ☐ Room Air (Use 29.0)

10. Condition which might affect measurements

____

11. Holes covered

☐ Complete

12. Atmospheric Pressure

__________ ("Hg) Barometer Location ______________

13. Post Measurement Verifications

☐ Manometer verification passed (within 5%) ☐ Manometer verification not required.

Test Number	Velocity Pressure (inches wg)			Static Pressure (inches wg)		
	Manometer	Reference	% Difference	Manometer	Reference	% Difference
1						
2						
3						

☐ Thermometer verification passed (within 1.5%)

Temperature Reading °F		Absolute Temperature °R		
		°R = °F + 460		
Thermometer	Reference	Thermometer	Reference	% Difference

Comments:

Flow measurements were made in accordance with the latest revision of MAQ-127.
Measurements by:

Signature	Print name	Z-Number	Date
			___/___/___

MAQ QA check by (initials):	MAQ review and approval by (initials):

Meteorology and Air Quality

Velocity Measurement Input Form (Form 5-R)

(2 x 12 Round Stack or Duct)

This form is from MAQ-127

TA/Building/ES ______-______-______ Measurement Date _____/_____/_____

Measurement Traverse A				Measurement Traverse B			
Point	Spacing (nearest 1/8 in)	Velocity Pressure (in H_2O)	Temperature (°F)	Point	Spacing (nearest 1/8 in)	Velocity Pressure (in H_2O)	Temperature (°F)
A1				B1			
A2				B2			
A3				B3			
A4				B4			
A5				B5			
A6				B6			
A7				B7			
A8				B8			
A9				B9			
A10				B10			
A11				B11			
A12				B12			
CP-A				CP-B			

Measurements by:

____________________ ____________________ ________________ _____/_____/_____

Signature Print name Z-Number Date

MAQ QA check by (initials):

MAQ review and approval by (initials):

Meteorology and Air Quality

Velocity Measurement Input Form (Form 5-S)

(6 x 5 Rectangular Stack or Duct)

This form is from MAQ-127

TA/Building/ES ______-______-______ Measurement Date _____/_____/_____

Measurement Traverse A				Measurement Traverse B			
Point	Spacing (nearest 1/8 in)	Velocity Pressure (in H_2O)	Temperature (°F)	Point	Spacing (nearest 1/8 in)	Velocity Pressure (in H_2O)	Temperature (°F)
A1				D1			
A2				D2			
A3				D3			
A4				D4			
A5				D5			
B1				E1			
B2				E2			
B3				E3			
B4				E4			
B5				E5			
C1				F1			
C2				F2			
C3				F3			
C4				F4			
C5				F5			

Measurements by:

______________________ ____________________________ _________________ ______/______/______

Signature Print name Z-Number Date

MAQ QA check by (initials):

MAQ review and approval by (initials):

Meteorology and Air Quality

Velocity Measurement Input Continuation Form (Form 5-C)

This form is from MAQ-127

TA/Building/ES ______-______-______ Measurement Date _____/_____/_____

Measurement Traverse ____				Measurement Traverse ____			
Point	Spacing (nearest 1/8 in)	Velocity Pressure (in H_2O)	Temperature (°F)	Point	Spacing (nearest 1/8 in)	Velocity Pressure (in H_2O)	Temperature (°F)
CP				CP			

Measurements by:

____________________ Signature ____________________ Print name ________________ Z-Number _____/_____/_____ Date

MAQ QA check by (initials):

MAQ review and approval by (initials):

Meteorology and Air Quality

Stack Flow Data Transcription and Entry Verification Form

This form is from MAQ-127

Place check in appropriate column:

Column 1: Data transcription verification **Column 2**: Data entry verification

1	2	Stack ID
		TA-03, bldg-0029, ES-14, config. # 02
		TA-03, bldg-0029, ES-15, config. # 01
		TA-03, bldg-0029, ES-19, config. # 01
		TA-03, bldg-0029, ES-20, config. # 01
		TA-03, bldg-0029, ES-23, config. # 01
		TA-03, bldg-0029, ES-24, config. # 01
		TA-03, bldg-0029, ES-28, config. # 01
		TA-03, bldg-0029, ES-29, config. # 01
		TA-03, bldg-0029, ES-32, config. # 01
		TA-03, bldg-0029, ES-33, config. # 01
		TA-03, bldg-0029, ES-37, config. # 01
		TA-03, bldg-0029, ES-44, config. # 02
		TA-03, bldg-0029, ES-45, config. # 02
		TA-03, bldg-0029, ES-46, config. # 02
		TA-03, bldg-0102, ES-22, config. # 01
		TA-03, bldg-0141, ES-01, config. # 01
		TA-03, bldg-0141, ES-01, config. # 02
		TA-16, bldg-0205, ES-04, config. # 02
		TA-21, bldg-0155, ES-05, config. # 01
		TA-21, bldg-0209, ES-01, config. # 01
		TA-33, bldg-0086, ES-06, config. # 01
		TA-33, bldg-0086, ES-06, config. # 02
		TA-33, bldg-0086, ES-06, config. # 03

1	2	Stack ID
		TA-41, bldg-0004, ES-17, config. #01
		TA-48, bldg-0001, ES-07, config. # 01
		TA-48, bldg-0001, ES-07, config. # 02
		TA-48, bldg-0001, ES-54, config. # 01
		TA-48, bldg-0001, ES-60, config. # 01
		TA-50, bldg-0001, ES-02, config. # 01
		TA-50, bldg-0037, ES-01, config. # 01
		TA-50, bldg-0069, ES-03, config. # 01
		TA-53, bldg-0003, ES-03, config. #
		TA-53, bldg-0003, ES-03, config. #
		TA-53, bldg-0003, ES-03, config. #
		TA-53, bldg-0003, ES-03, config. #
		TA-53, bldg-0007, ES-02, config. #
		TA-53, bldg-0007, ES-02, config. #
		TA-53, bldg-0007, ES-02, config. #
		TA-53, bldg-0007, ES-02, config. #
		TA-53, bldg-0007, ES-02, config. #
		TA-53, bldg-0007, ES-02, config. #
		TA-53, bldg-0007, ES-02, config. #
		TA-55, bldg-0004, ES-15, config. # 01
		TA-55, bldg-0004, ES-16, config. # 01

For the stacks checked above in **column 1**, I have performed a 100% verification to ensure the data have been **transcribed** correctly from the “raw” data forms to the “official” records form. The parameters verified are the duct static pressure, cross-sectional area of the duct/stack, atmospheric pressure, temperature of air in the stack, and the velocity pressure readings.

________________ ____________________ ____________ _____/_____/_____

Signature Print name Z-Number Date

For the stacks checked above in **column 2**, I have performed a 100% verification to ensure the **data entered** into the “Stack” database corresponds to the data collected in the field. The parameters verified are the duct static pressure, cross-sectional area of the duct/stack, atmospheric pressure, temperature of air in the stack, and the velocity pressure readings.

________________ ____________________ ____________ _____/_____/_____

Signature Print name Z-Number Date

Meteorology and Air Quality

Flow Measurement Calculation Form (Form 6)

This form is from MAQ-127

TA/Building/ES ______-______-______ FE(s) ________________________

Measurement Date _____/_____/_____ Fan Exhaust Configuration _________

Profile Measurement Number _________

Step 1: Calculate the stack gas average absolute temperature, $T_{s(avg)}$

a) From field input form, determine $t_{s(avg)}$ = _________ °F

b) Calculate the absolute temperature, $T_{s(avg)} = t_{s(avg)} + 460$ = ________ °R

Step 2: Calculate the exhaust stack absolute pressure, P_s

b) From the field input form, record the barometric reference pressure, P_{ref} = _________ " Hg

b) Adjusting for elevation,

$P_{bar} = P_{ref}$ + [Elevation $_{profile}$ - Elevation $_{ref}$] (-0.1 "Hg / 100 ft)

= _______ "Hg + [___________ ft - ________ ft] (-0.1/100)

= _____________ "Hg

d) From the field input form, record the stack static pressure, P_g = __________ " wg

e) Convert the static pressure from inches w.g. to inches Hg

P_g = [P_g"wg] (62.4 / 846.9) "Hg

= __________ (62.4 / 846.9) "Hg

= __________ "Hg

f) Calculate the exhaust stack absolute pressure

$P_s = P_{bar} + P_g$

= ________ + ________ = ________ "Hg

Step 3: Calculate the molecular weight of the stack gas, M_s

a) From Method 4 or 5 B_{ws} = __________ (**Always** use 0 humidity for conservatism)

b) From Method 3 M_d = __________ (Use 29 for air)

d) Calculate M_s $M_s = M_d (1 - B_{ws}) + 18.0\ B_{ws}$

= ________ (1 - ________) + 18.0 (________)

= ________ lb / lb mole

Flow Measurement Calculation Form (Form 6), continued

Step 4: Calculate K

a) K = (85.49) (60) SQRT[$T_{s(avg)}$ / $P_s M_s$]

= (85.49)(60) SQRT [________ / (________)(________)] = ____________

Step 5: From the field input form, calculate the average velocity head of the stack gas

a) $$(\sqrt{\Delta p})_{(avg)} = \frac{\sum_{i=1}^{n} \sqrt{\Delta p}}{n}$$ = __________ inches water

Step 6: Calculate the average stack gas velocity (actual), v_s

a) $$v_s = C_p \, K \, (\sqrt{\Delta p})_{avg}$$ ft/min

= ________ * ________ * ________

= ________ ft/min

Step 7: Calculate the exhaust stack flow rate (actual), Q

b) Record the stack/duct cross-sectional area from profile measurements

A = __________ ft^2

c) Q = v_s * A

= ________ * ________

= ________ acfm

Step 8: Calculate the exhaust stack gas dry volumetric flow rate (standard), Qsd

a) $$Q_{sd} = (1 - B_{ws}) \, v_s A \, \frac{T_{std}}{T_{s(avg)}} \, \frac{P_s}{P_{std}}$$

Q_{sd} = [1 - ________] * ________ * ________ [________ / ________] [________ / ________]

Q_{sd} = ____________ scfm

Calculations by:

____________________	___________________________	________________	_____/_____/_____
Signature	Print name	Z-Number	Date

MAQ QA check by (initials):	MAQ review and approval by (initials):

Cross-Sectional Area Worksheet (Round Exhaust Stack or Duct) (Form 7-R)

This form is from MAQ-127

TA/Building/ES ______-______-______ FE(s) ________________________

Profile Measurement Number __________

1. Sketch the exhaust stack or duct cross- section and label the traverses. Include any references in the sketch.

2. Measure the diameters to the nearest 1/8 inch

Traverse Number	Measured Diameter (nearest 1/8")	Diameter (decimal format in inches)
d_1		
d_2		
d_3		
d_4		

Measurements by:

____________________ ________________________ ______________ _____/_____/_____

Signature Print name Z-Number Date

3. Calculate the cross- sectional area. Do not round d or π. Round final number to three decimal places.

Round: $Area = \pi\left[\frac{d}{2}\right]^2\left[\frac{1}{144}\right]$ **OR** Oval: $Area = \frac{\pi * d_1 * d_2}{576}$ Area = ________________ sq feet

Calculations by:

____________________ ________________________ ______________ _____/_____/_____

Signature Print name Z-Number Date

MAQ QA check by (initials):

MAQ review and approval by (initials):

Meteorology and Air Quality

Cross-Sectional Area Worksheet (Rectangular Exhaust Stack or Duct) (Form 7-S)

This form is from MAQ-127

TA/Building/ES ______-______-______ FE(s) ________________________

Profile Measurement Number __________

1. Sketch the exhaust stack or duct cross- section and label the traverses. Include any references in the sketch.

2. Measure the widths and depths to the nearest 1/8 inch

Traverse Number	Measured Diameter (nearest 1/8”)	Diameter (decimal format in inches)
Width 1 (W1)		
Width 2 (W2)		
Depth 1 (D1)		
Depth 2 (D2)		

Measurements by:

____________________ ____________________ ____________________ _____/_____/_____

Signature Print name Z-Number Date

3. Calculate the cross- sectional area. Round final number to three decimal places.

$$Area = \left[\frac{W1+W2}{2}\right]\left[\frac{D1+D2}{2}\right]\left[\frac{1}{144}\right]$$ sq feet

Area = ________________ sq feet

Calculations Performed by:

____________________ ____________________ ____________________ _____/_____/_____

Signature Print name Z-Number Date

MAQ QA check by (initials):	MAQ review and approval by (initials):